

(12) **United States Patent**  
**Bottasso**

(10) **Patent No.:** **US 11,618,558 B2**  
(45) **Date of Patent:** **Apr. 4, 2023**

(54) **ROTOR FOR A HOVER-CAPABLE AIRCRAFT AND RELATED METHOD OF CONTROL**

(58) **Field of Classification Search**  
None  
See application file for complete search history.

(71) Applicant: **LEONARDO S.P.A.**, Rome (IT)  
(72) Inventor: **Luigi Maria Bottasso**, Samarate (IT)  
(73) Assignee: **LEONARDO S.P.A.**, Rome (IT)

(56) **References Cited**

(\*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 92 days.

**U.S. PATENT DOCUMENTS**  
4,722,499 A \* 2/1988 Klug ..... B64C 23/076  
244/45 R  
6,345,790 B1 \* 2/2002 Brix ..... B64C 23/076  
244/46  
6,467,732 B2 \* 10/2002 Tsukahara ..... B64C 27/463  
244/17.11

(21) Appl. No.: **17/237,520**

(Continued)

(22) Filed: **Apr. 22, 2021**

**FOREIGN PATENT DOCUMENTS**

(65) **Prior Publication Data**

CN 1185399 6/1998  
DE 3100800 1/1982

US 2021/0253229 A1 Aug. 19, 2021

(Continued)

**Related U.S. Application Data**

*Primary Examiner* — Juan G Flores  
(74) *Attorney, Agent, or Firm* — Leason Ellis LLP

(62) Division of application No. 16/328,069, filed as application No. PCT/EP2017/072496 on Sep. 7, 2017, now Pat. No. 11,014,660.

**Foreign Application Priority Data**

(57) **ABSTRACT**

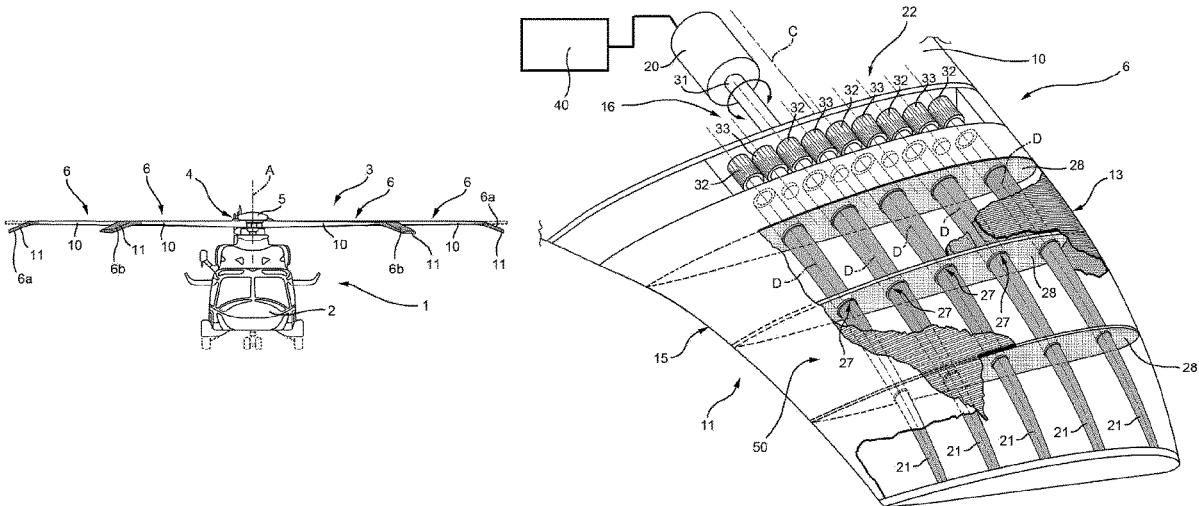
Sep. 7, 2016 (EP) ..... 16187546

A rotor for a hover-capable aircraft is described that comprises: a hub rotatable about a first axis and at least two blades hinged to the hub; each blade comprises a main portion hinged to the hub and a tip portion, which is arranged radially outermost with respect to first axis with respect to the corresponding main portion; the tip portion of each blade is movable with respect to the corresponding main portion of that blade; the tip portion of each blade is selectively movable with respect to the corresponding main portion of that blade between a first position, in which it defines a dihedral or anhedral angle with respect to the corresponding main portion; and a second position, in which it defines a positive or negative sweep angle with respect to the corresponding main portion.

(51) **Int. Cl.**  
**B64C 27/46** (2006.01)  
**B64C 27/04** (2006.01)  
**B64C 27/59** (2006.01)  
**B64C 27/72** (2006.01)

(52) **U.S. Cl.**  
CPC ..... **B64C 27/463** (2013.01); **B64C 27/04** (2013.01); **B64C 27/59** (2013.01); **B64C 27/72** (2013.01); **B64C 2027/7211** (2013.01)

**10 Claims, 16 Drawing Sheets**



(56)

**References Cited**

U.S. PATENT DOCUMENTS

7,264,200 B2 \* 9/2007 Bussom ..... B64C 23/072  
416/24  
10,106,251 B2 \* 10/2018 Foskey ..... B64C 27/463  
2006/0027703 A1 \* 2/2006 Bussom ..... B64C 23/072  
244/17.13  
2007/0212223 A1 9/2007 Moffitt et al.  
2016/0075430 A1 \* 3/2016 Foskey ..... B64C 27/463  
416/1

FOREIGN PATENT DOCUMENTS

EP 1 127 786 8/2001  
EP 1771331 4/2007  
EP 2 228 299 9/2010  
KR 2012 0059091 6/2012

\* cited by examiner

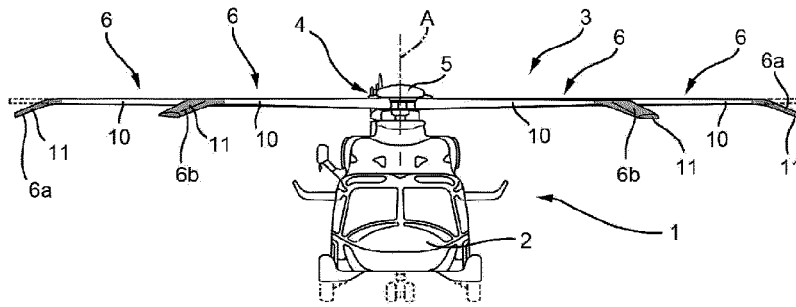


FIG. 1

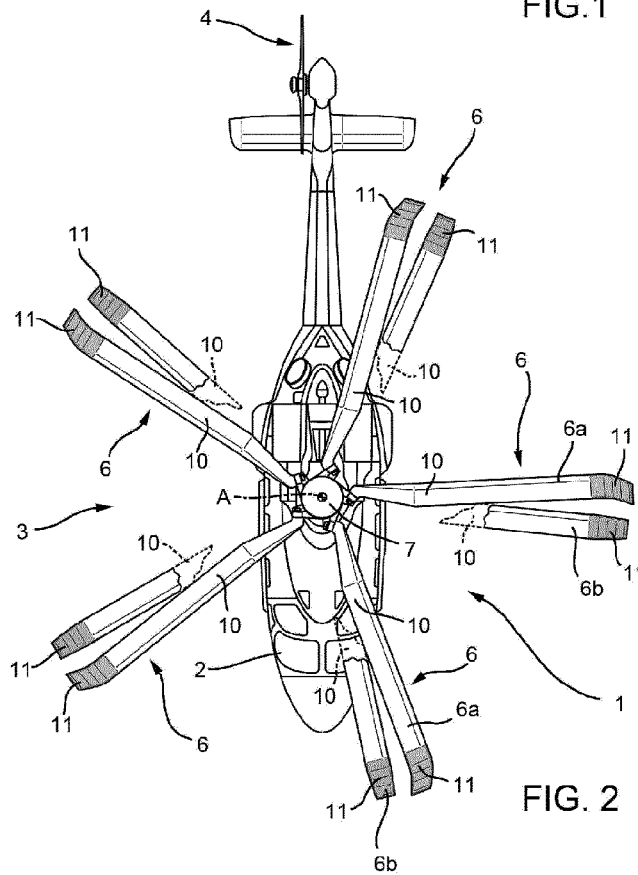
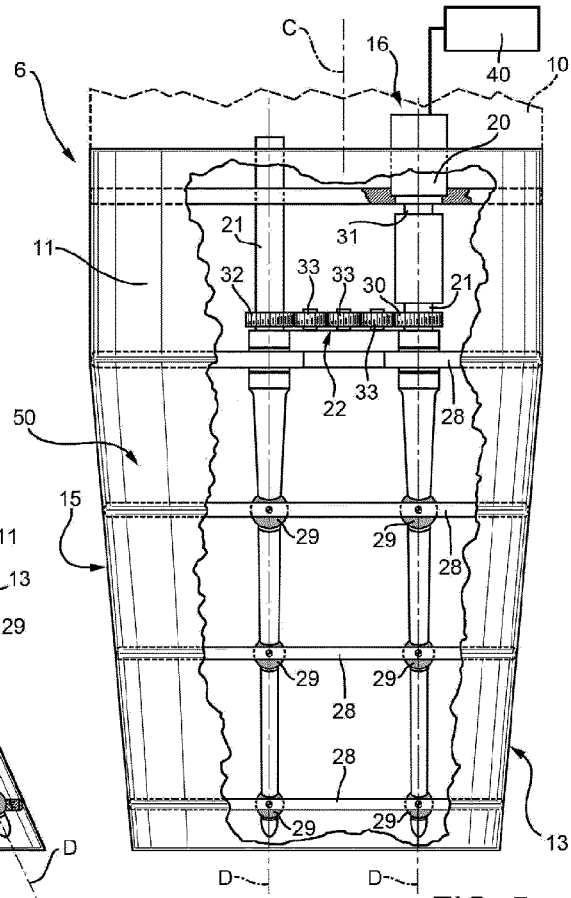
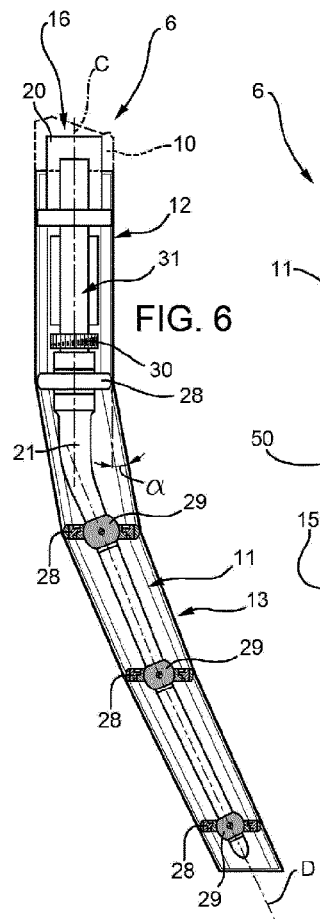
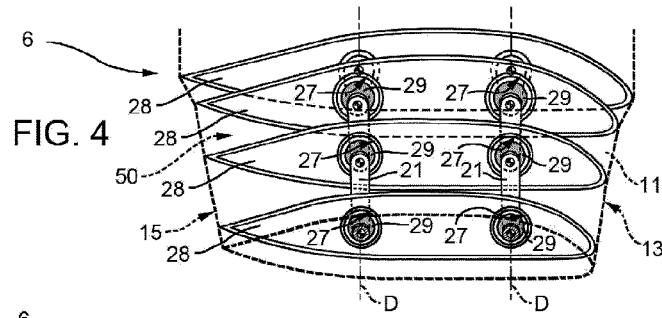


FIG. 2









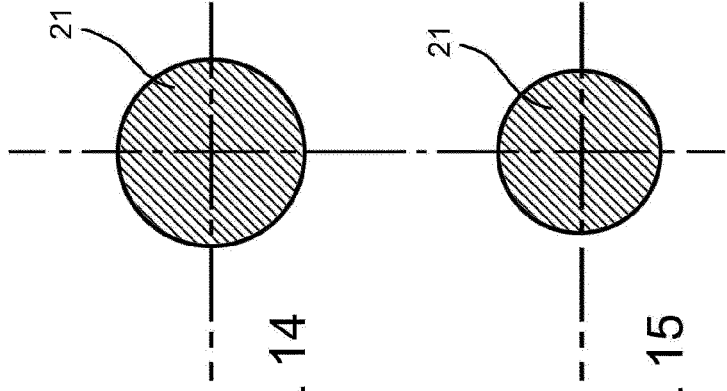
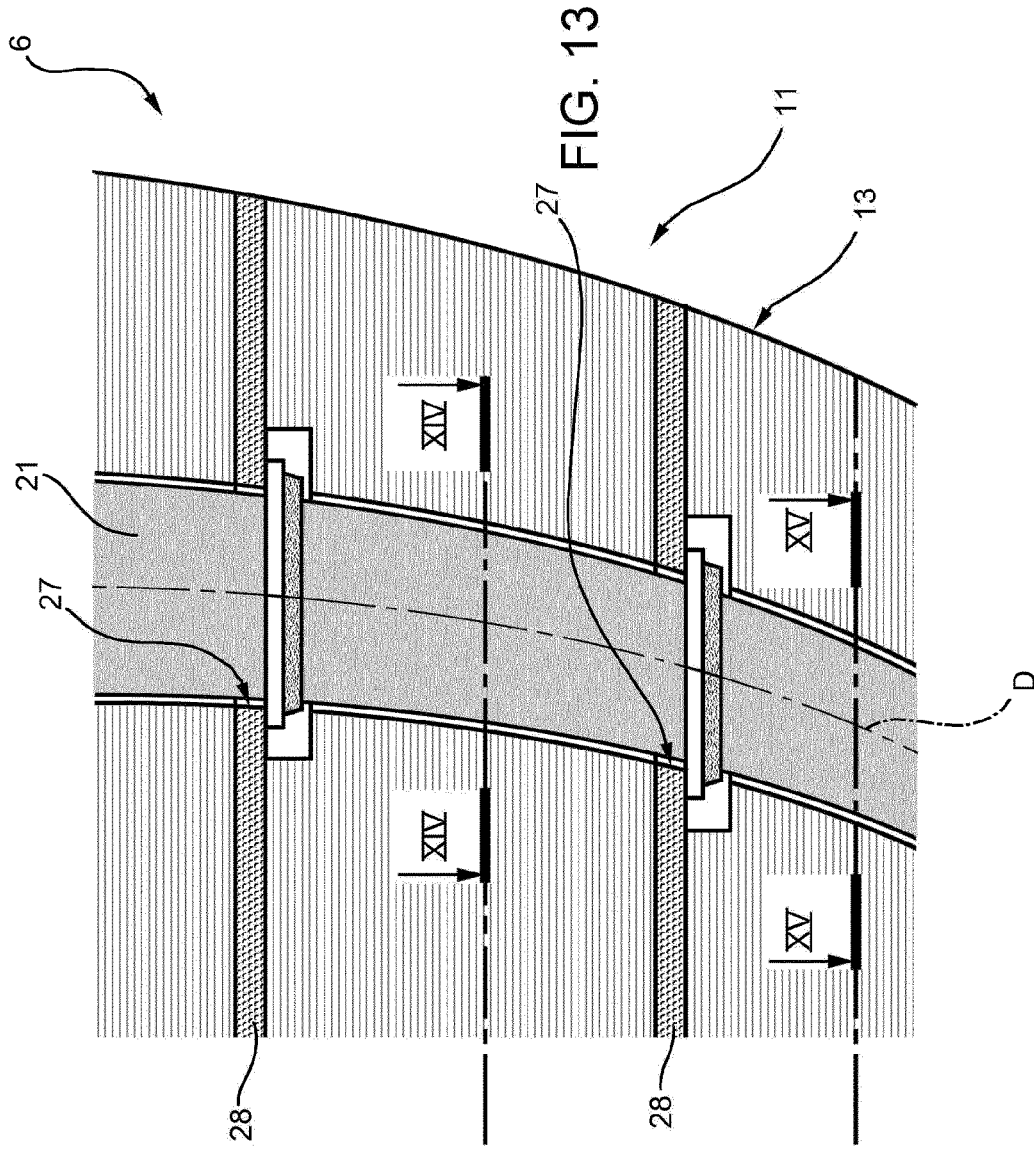


FIG. 14

FIG. 15

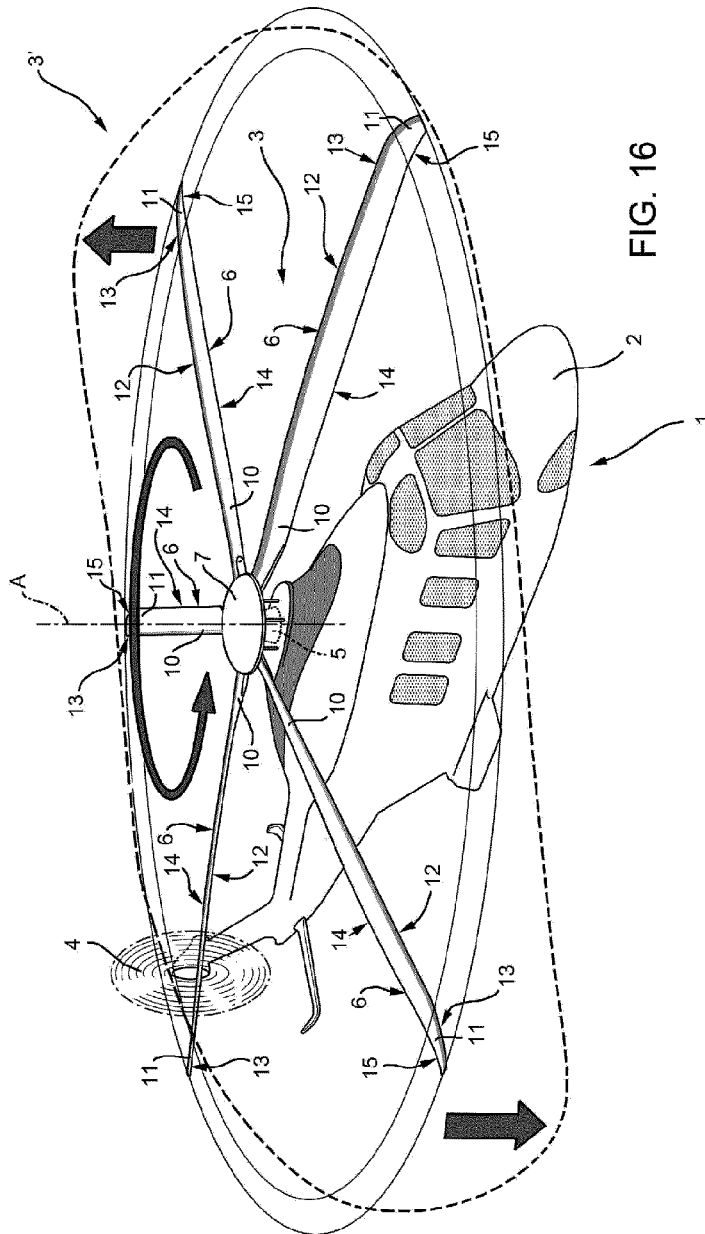
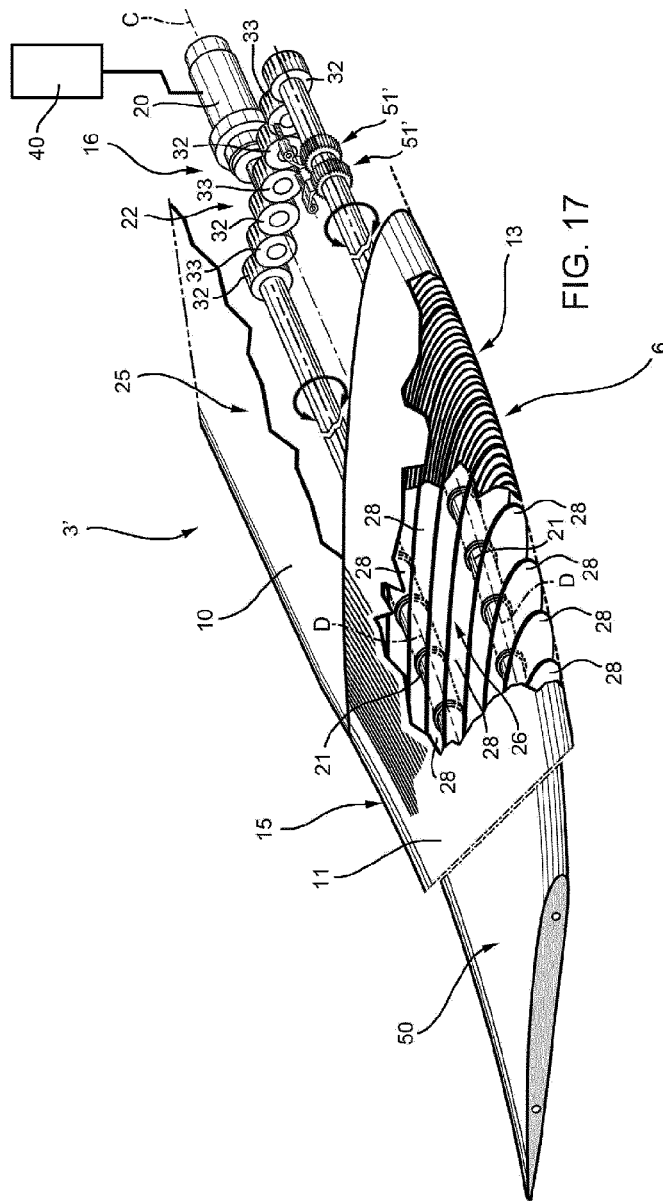
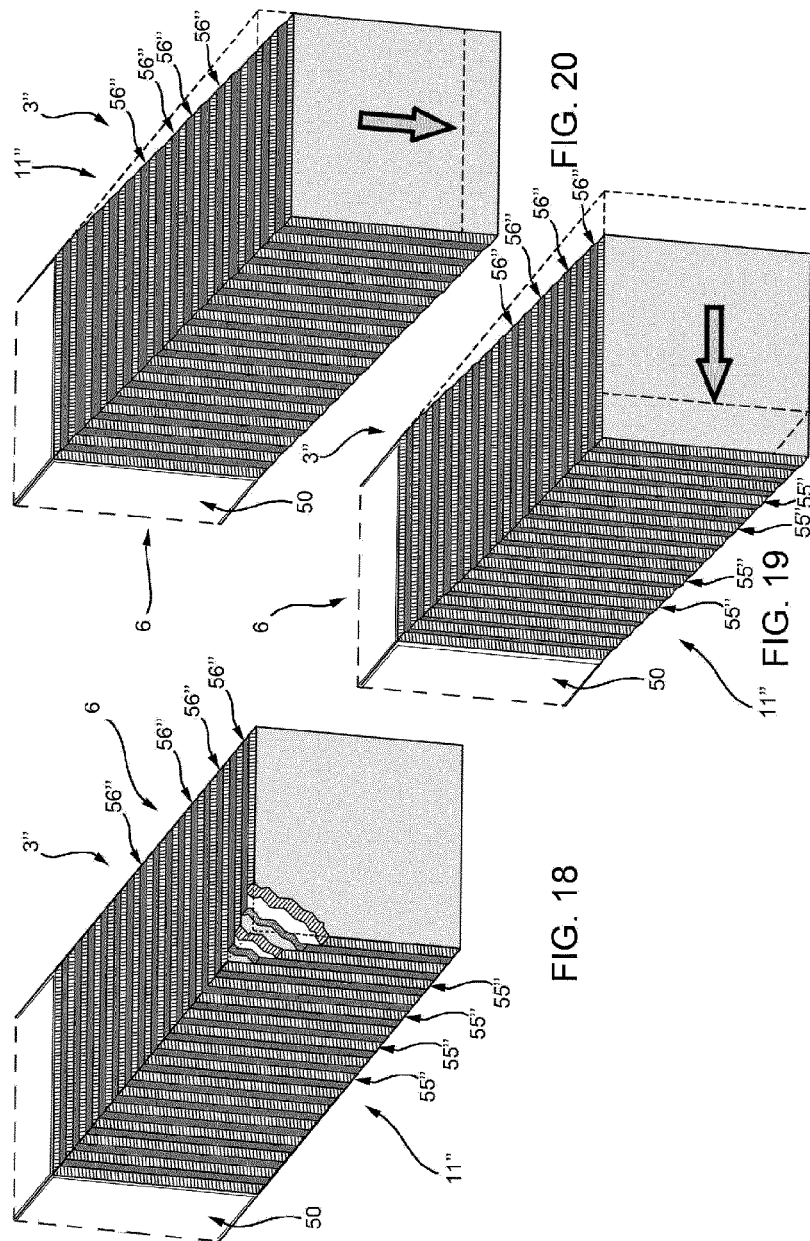


FIG. 16





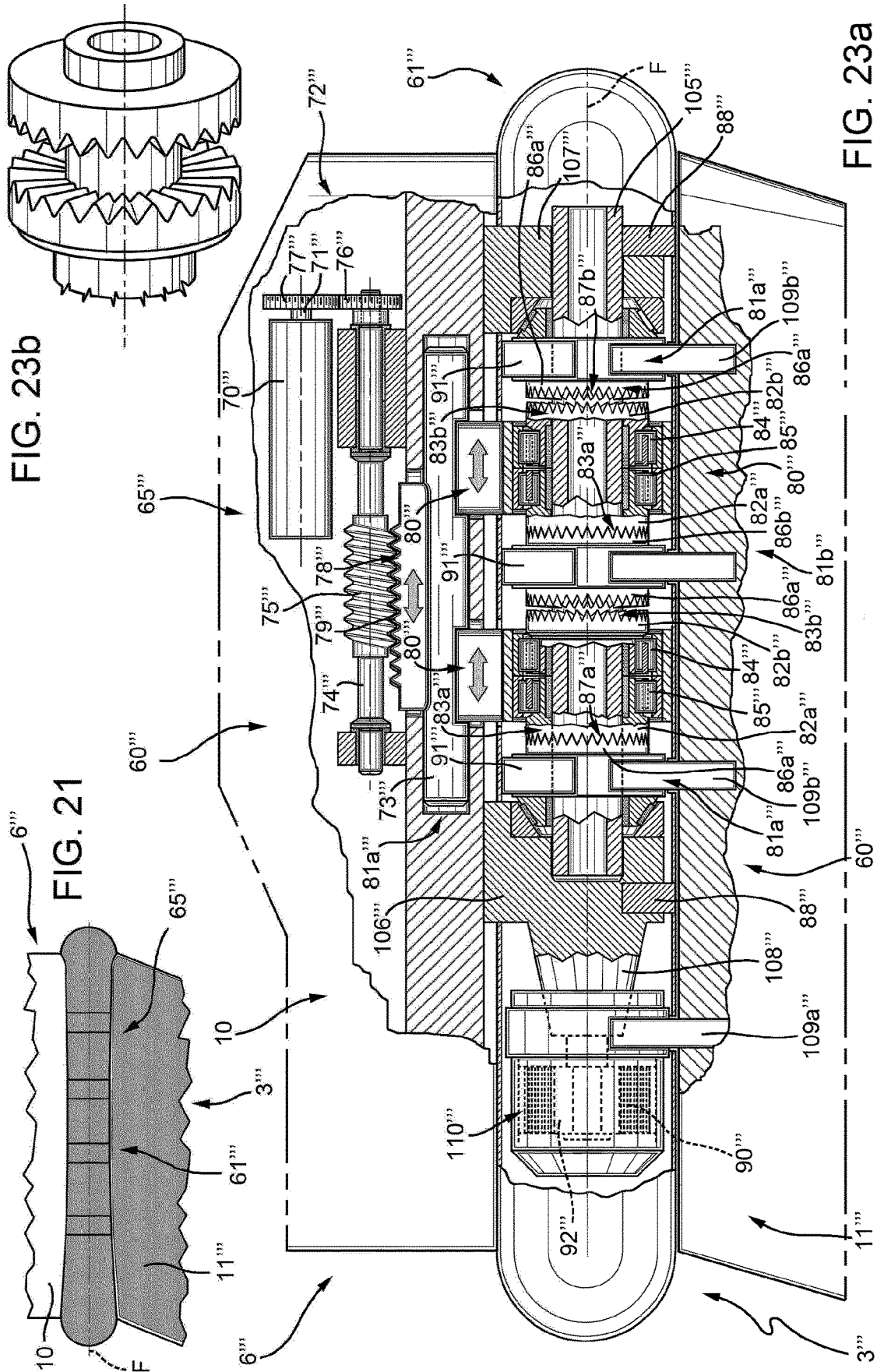


FIG. 23b

FIG. 21

FIG. 23a

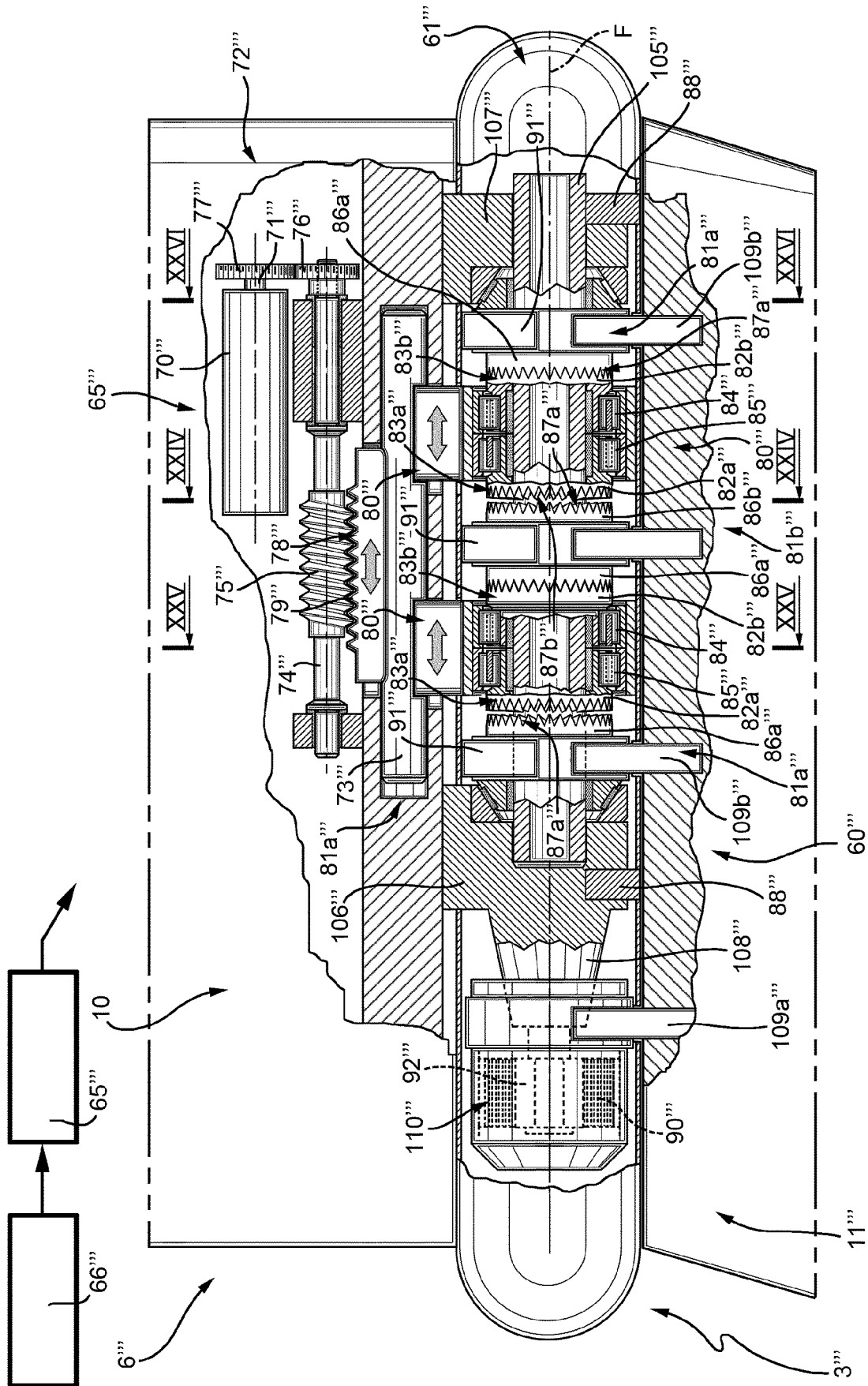


FIG. 22

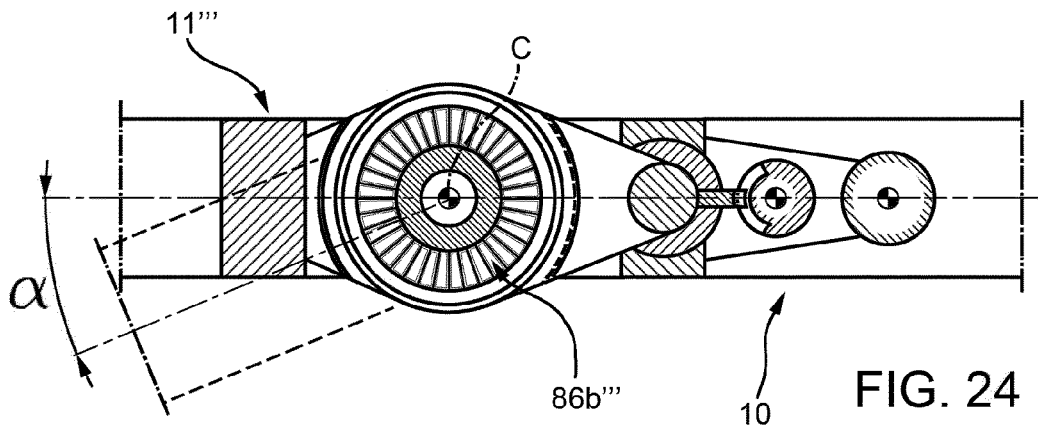


FIG. 24

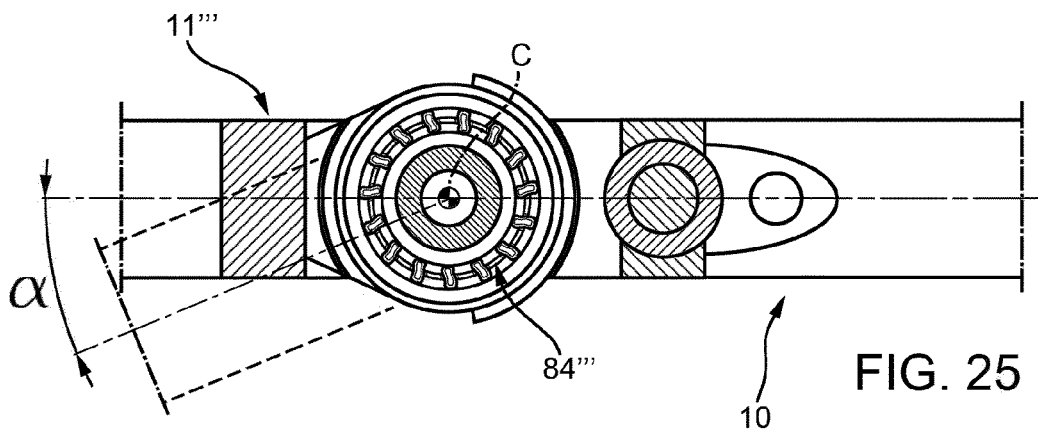


FIG. 25

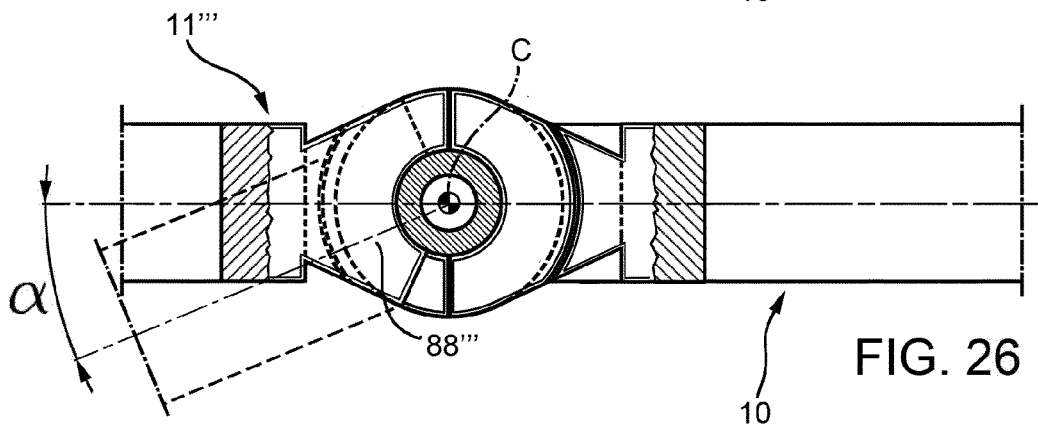


FIG. 26

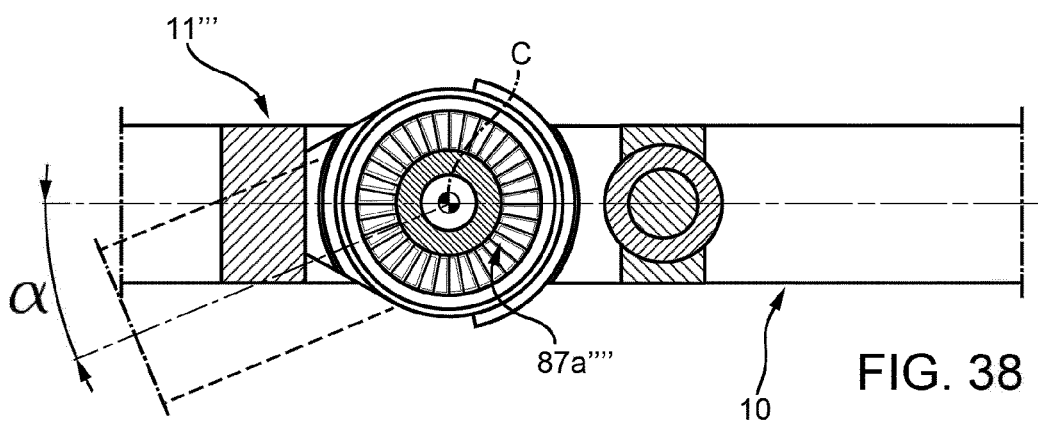


FIG. 38

Hover

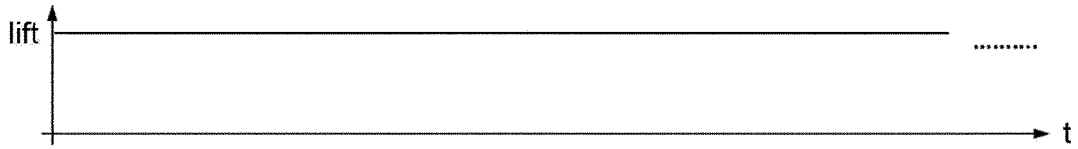


FIG. 27

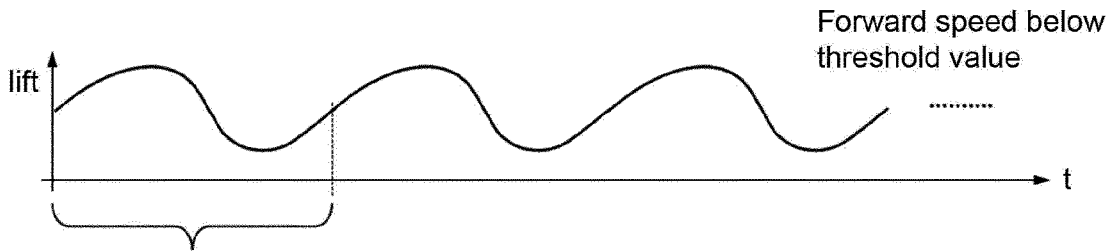


FIG. 28

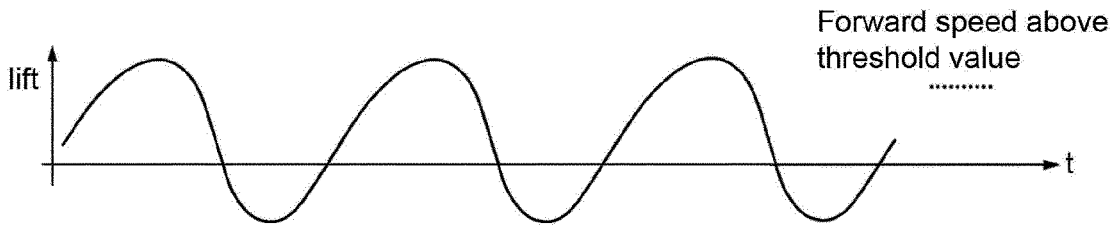


FIG. 29

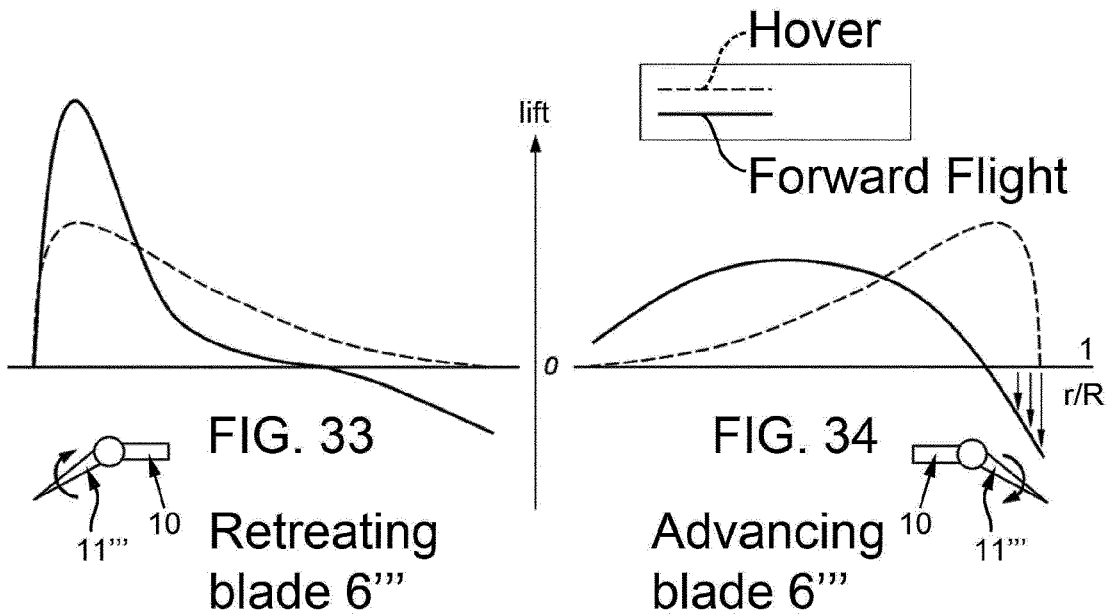
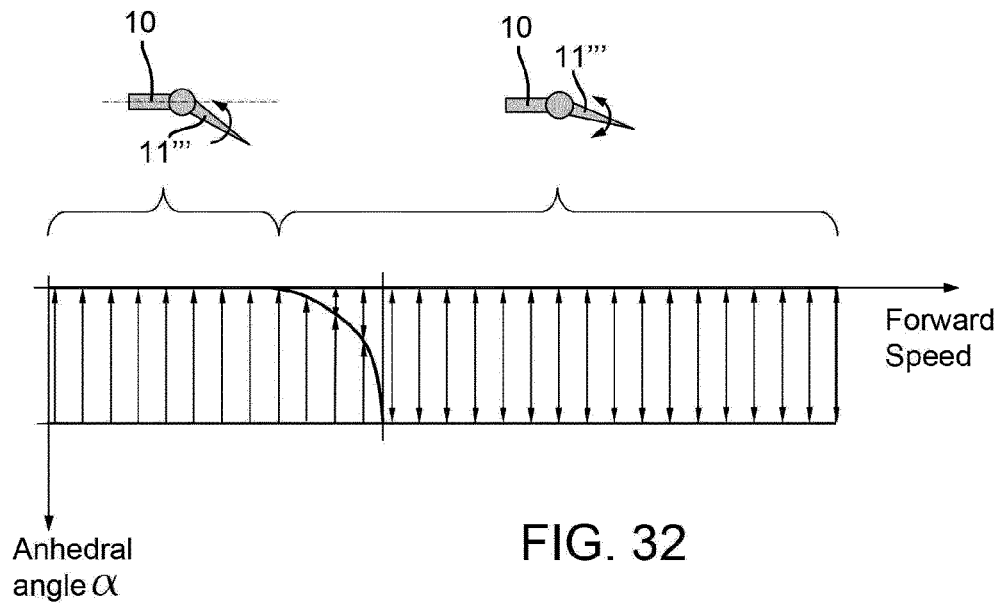
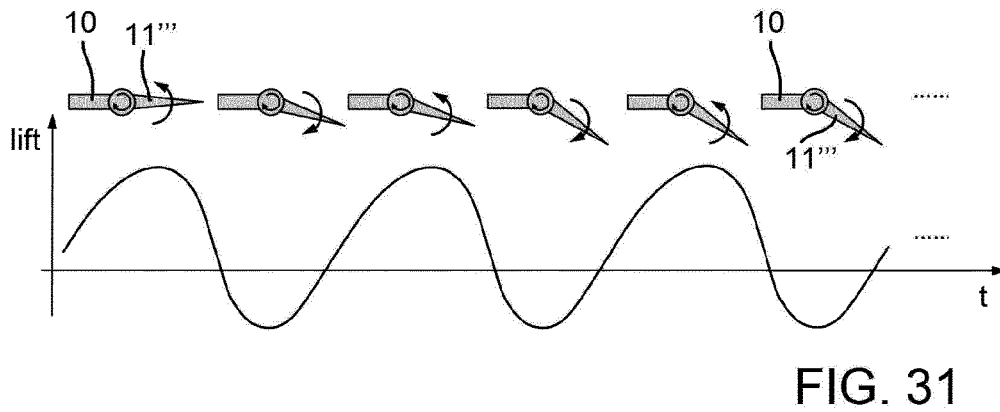
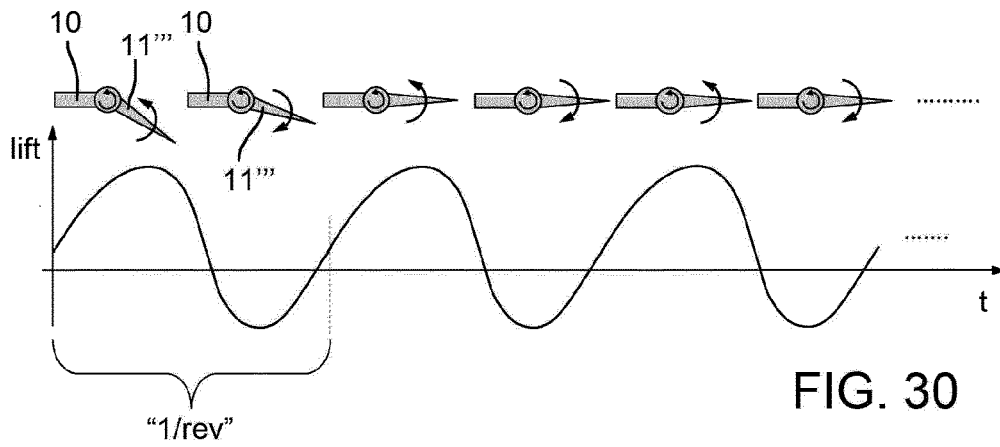


FIG. 33  
Retreating  
blade 6'''"

FIG. 34  
Advancing  
blade 6'''"



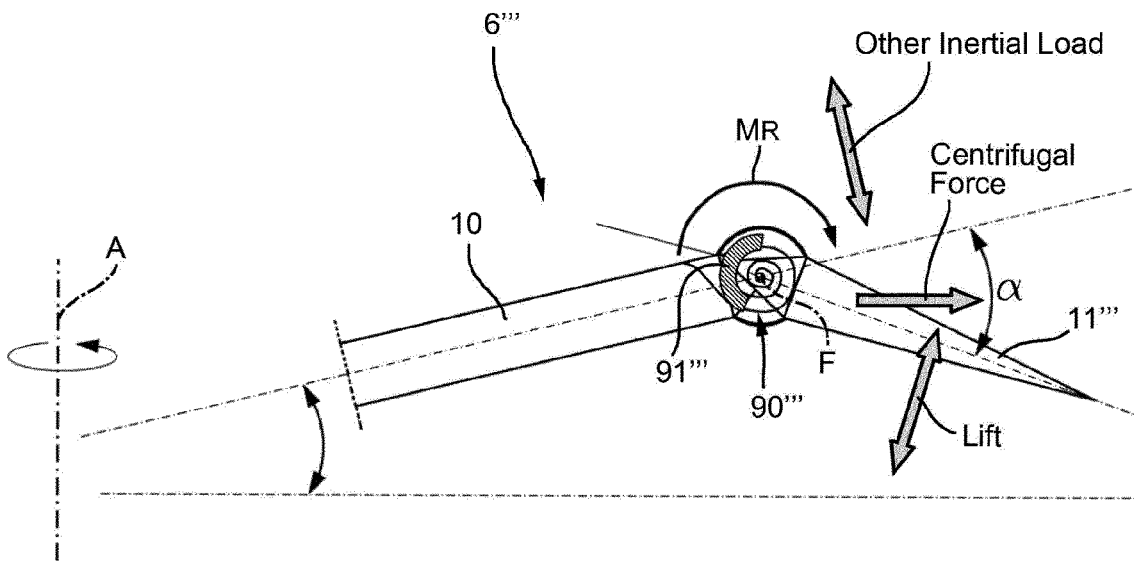


FIG. 35

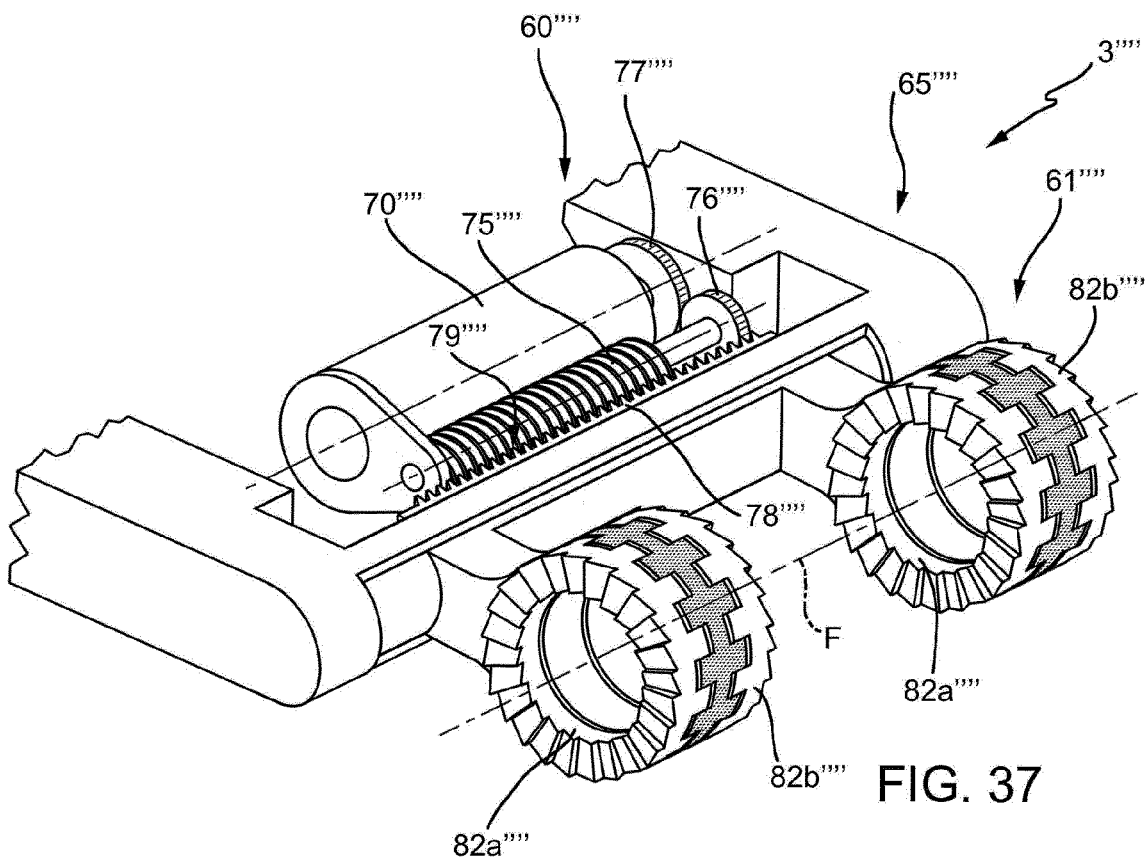


FIG. 37

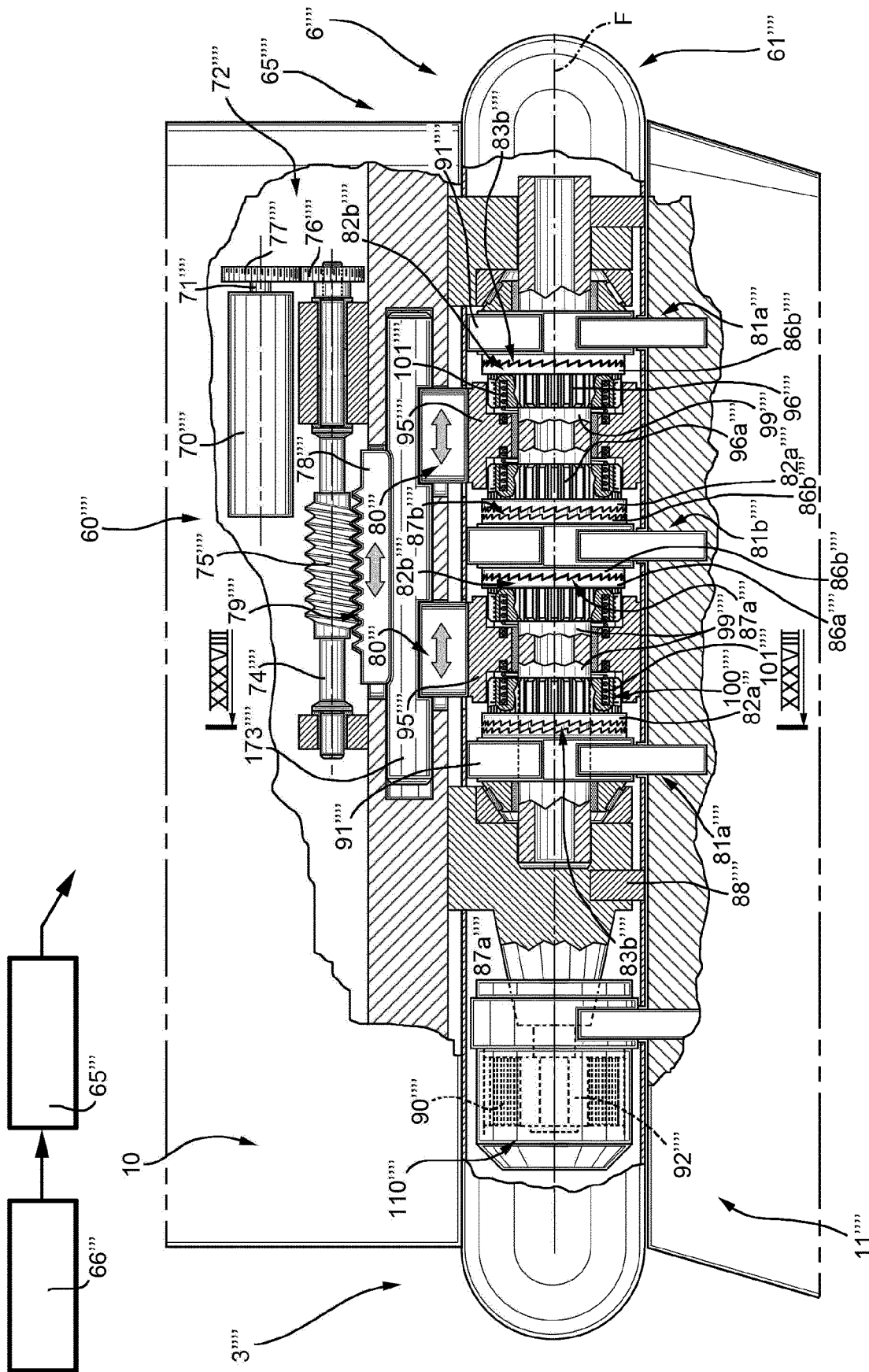


FIG. 36

**ROTOR FOR A HOVER-CAPABLE  
AIRCRAFT AND RELATED METHOD OF  
CONTROL**

CROSS-REFERENCE TO RELATED PATENT  
APPLICATIONS

This application is a divisional of U.S. application Ser. No. 16/328,069, filed Feb. 25, 2019, which is a U.S. National Phase Application under 35 U.S.C. § 371 of International Patent Application No. PCT/EP2017/072496, filed Sep. 7, 2017, which claims the priority of European Application No. 16187546.3, filed Sep. 7, 2016, which is incorporated by reference as if expressly set forth in its entirety herein.

TECHNICAL FIELD

The present invention relates to a rotor for a hover-capable aircraft.

The present invention also relates to a method of controlling a rotor for a hover-capable aircraft.

BACKGROUND ART

Known hover-capable aircrafts, such as helicopters for example, comprise a fuselage, a main rotor positioned on the top of a central portion of the fuselage and an anti-torque tail rotor with the function of countering the torque generated by the main rotor on the fuselage.

The main rotor basically comprises a mast rotatable about an axis, a hub coupled to this mast, and a plurality of blades fastened in a cantilever manner to the above-mentioned hub.

In particular, each blade has a substantially longitudinal extension radial to the axis of the mast and, in use, is driven in rotation by the hub on a motion plane transversal to the axis of the mast.

In addition, each blade is movable with respect to the hub on some or all of the orientation planes so as to enable the different manoeuvres of the helicopter.

Each blade comprises, in particular:

a main portion defining a root of the blade, which is hinged to the hub; and

a tip portion, which delimits the blade at the far end from the mast with respect to the main portion.

The main portion of each blade is longer than the corresponding tip portion.

In the helicopter industry, it is known to shape the tip portions of the blades with an anhedral (negative dihedral) angle with respect to the corresponding main portions. In other words, the tip portions of the blades are inclined downwards from the corresponding main portions and towards the fuselage of the helicopter.

Thanks to the presence of an anhedral angle, it is possible to improve the figure of merit in the helicopter's hovering conditions.

Despite enabling the behaviour of the helicopter to be improved in hovering conditions, the use of tip portions having anhedral angles makes the helicopter noisier in forward flight conditions.

In the industry, there is a need to make rotors for hover-capable aircraft that enable both preserving aerodynamic efficiency in hovering conditions and reducing noise in forward flight conditions.

More specifically, there is a need to make rotors of the above-identified type while containing as far as possible the displacement of the barycentre of the tip portions of the

blades. This is in order to avoid having to counter high loads due to centrifugal acceleration, which can reach several hundreds of g on the tip portions.

In addition, there is a need to make rotors of the above-identified type that employ moderate actuating forces and/or without unbalancing the rotor in the event of erroneous control of one of the blades and/or without altering the aerodynamic profile of the blades, and therefore without penalizing the overall aerodynamic efficiency of the helicopter.

US2016/0075430 describes a rotor for a hover-capable aircraft in which each blade of the rotor comprises a tip portion hinged to a main root portion, and which can be operated to adjust the anhedral angle according to the flight conditions of the aircraft.

The rotor shown in US2016/0075430 further comprises a hydraulic actuator for adjusting the anhedral angle of the tip portion.

However, the use of power operated actuators for controlling the anhedral angle of the tip portion leaves room for improvement.

In particular, it is difficult to house an actuator within the small-sized region between the main blade portion and the tip portion.

Furthermore, the tip portions are subjected to very high aerodynamic and inertial loads, in particular centrifugal forces. Accordingly, the actuating system requires very powerful actuating forces and torques.

A need is therefore also felt within the industry to selectively adjust the angle between the tip portion and main portion, which requires as little as possible the use of power operated actuators.

KR-A-20120059091 discloses a rotor according to the preamble of claim 1.

EP-A-1127786 discloses a base wing, which is attached at its root end portion to the rotor head of a rotational drive unit and is provided with a front wing and a rear wing having substantially equal spans. EP-A-1127786 discloses a control unit for controlling the incidence angle of the front and rear wings.

US-A-2006/027703 discloses a blade comprising a main portion, a tip portion having an aerodynamic shape and positioned proximate to an edge of the main portion, an actuator coupled to the tip portion. The actuator is configured to rotate the tip portion about a longitudinal axis thereof and to adjust a dihedral angle of the tip portion.

EP-A-2228299 discloses a rotor for a hover-capable aircraft according to the preamble of claim 24 and a method of controlling a rotor for a hover-capable aircraft according to the preamble of claim 34.

DISCLOSURE OF INVENTION

The object of the present invention is to produce a rotor for an aircraft capable of hovering that satisfies at least one of the above-specified needs in a simple and inexpensive manner.

The aforesaid object is achieved by the present invention, in so far as it relates to a rotor for a hover-capable aircraft, as claimed in claim 1.

The present invention also relates to a method of controlling a rotor for a hover-capable aircraft, as claimed in claim 19.

The present invention also relates to a rotor for a hover-capable aircraft, as claimed in claim 24 or 32.

The present invention also relates to a method of controlling a rotor for a hover-capable aircraft, as claimed in claim **35** or **45**.

#### BRIEF DESCRIPTION OF THE DRAWINGS

For a better understanding of the present invention, four preferred embodiments are described hereinafter, purely by way of non-limitative example and with reference to the accompanying drawings, in which:

FIG. **1** is a front view of a helicopter comprising a rotor according to a first embodiment of the present invention equipped with blades arranged in a first operating condition of hovering and in a second operating condition of forward flight;

FIG. **2** is a top view of the helicopter in FIG. **1** showing the blades in the first and second operating conditions;

FIG. **3** is a perspective view on a highly enlarged scale of a blade of the rotor of the helicopter in FIGS. **1** and **2**, with parts removed for clarity;

FIG. **4** is a view taken from one side of the helicopter and on a still further enlarged scale of the blade in FIG. **3** in the first operating condition, with parts removed for clarity;

FIG. **5** is a view taken from above the helicopter of the blade in FIG. **4** in the first operating condition;

FIG. **6** is a view taken from the front of the helicopter of the blade in FIGS. **4** and **5** in the first operating condition;

FIG. **7** is a view taken from one side of the helicopter and on a still further enlarged scale of the blade in FIG. **3** in the second operating condition;

FIG. **8** is a view taken from above the helicopter of the blade in FIG. **7** in the first operating condition;

FIG. **9** is a view taken from the front of the helicopter of the blade in FIGS. **7** and **8** in the first operating condition;

FIG. **10** is a perspective view of the blade in FIGS. **4** to **9** in the first operating condition, with parts removed for clarity;

FIG. **11** is a perspective view of the blade in FIGS. **4** to **10** in the second operating condition, with parts removed for clarity;

FIG. **12** is a cross-section of the blade in FIGS. **4** to **11** along line XII-XII in FIG. **11**;

FIG. **13** is a longitudinal section of the blade in FIGS. **4** to **12** along line XIII-XIII in FIG. **11**;

FIGS. **14** and **15** are cross-sections of the blade in FIGS. **4** to **14** along lines XIV-XIV and XV-XV in FIG. **13**, respectively;

FIG. **16** shows a helicopter comprising a rotor according to a second embodiment of the present invention;

FIG. **17** shows a perspective view, on a highly enlarged scale, of a blade of the rotor in FIG. **16**, with parts removed for clarity; and

FIGS. **18** to **20** schematically show the shape of the blade of a rotor according to a third embodiment of the invention, with parts removed for clarity;

FIG. **21** shows a blade of a rotor according to a fourth embodiment of the present invention in a first configuration;

FIGS. **22** and **23a** are partially sectioned views of the blade of FIG. **21** in a first position and in a second position respectively, in enlarged view and parts removed for clarity;

FIG. **23b** is an enlarged view of some components of FIG. **23a**;

FIGS. **24** to **26** are sections taken along respective lines XXIV-XXIV and XXV-XXV and XXVI-XXVI of FIG. **22**;

FIGS. **27** to **29** show the temporal variation of the lift acting on the tip portions of the blade of FIGS. **21** to **23a**,

when the helicopter is respectively in hover, in forward flight at a speed below a threshold value and at a speed above the threshold value;

FIG. **30** shows the aerodynamic moment acting on the tip of the blade of FIGS. **21** to **23a** during the transition from the first position to the second position in the condition of FIG. **27**;

FIG. **31** shows the aerodynamic moment acting on the tip of the blade of FIGS. **21** to **23a** during the transition from the second position to the first position in the condition of FIG. **27**;

FIG. **32** shows the movement of the tip between the first and the second position as a function of the forward speed of the helicopter;

FIGS. **33** and **34** show the lift distribution along the span of the blade of FIGS. **21** to **23a** in a solid line with reference to a forward flight and in dotted line with reference to an hovering condition, respectively for a retreating blade and an advancing blade;

FIG. **35** shows the forces acting on the tip portion of the blade of FIGS. **21** to **23a** together with further components of this blade;

FIG. **36** is a partially sectioned view of a blade of a rotor according to a fifth embodiment of the present invention in a first position;

FIG. **37** is a perspective view of a tip portion of the blade of FIG. **36**, with parts removed for clarity and in an enlarged view; and

FIG. **38** is a section taken along lines XXXVIII-XXXVIII of FIG. **36**.

#### BEST MODE FOR CARRYING OUT THE INVENTION

Referring to FIGS. **1** and **2**, reference numeral **1** indicates a helicopter. The helicopter **1** basically comprises a fuselage **2**, a main rotor **3** rotating about an axis and a tail rotor **4** located at one end of the fuselage **2** and rotating about its own axis transversal to axis A. In particular, the anti-torque tail rotor **4** projects in a cantilever manner from a fin situated at a tail end of the fuselage **2** and is designed to counter the torque transmitted by the rotor **3** to the fuselage **2**.

In greater detail, the rotor **3** basically comprises:

a mast **5** rotating about an axis A transversal to the axis of rotation of the main rotor;

a plurality of blades **6**, five in the case shown, extending along respective directions substantially radial to axis A; and

a hub **7** operatively connected to the mast **5** and from which the blades **6** extend in a cantilever manner.

In greater detail, the hub **7** drives the blades **6** in rotation about axis A and enables the blades **6** to rotate, under the action of an external drive, about respective directions of extension to vary the respective angles of attack with respect to the airflow.

The blades **6** are hinged to the hub **7** so as to be movable about different axes, according to the configuration of the rotor **3**.

In the following description, reference will be made to only one blade **6**, as the blades **6** are all identical.

The blade **6** comprises:

a main portion **10** defining a root of the blade **6** hinged to the hub **7** and extending along an axis C (FIGS. **3** to **8**) transversal to axis A; and

a tip portion **11** arranged at the far end of the main portion **10** with respect to the tip portion **11**.

The main portion **10** is longer than the tip portion **11** in the direction of radial extension of the blade **6**.

The tip portion **11** is movable with respect to the main portion **10**.

Advantageously, the tip portion **11** is selectively movable with respect to the main portion **10** between:

- a first position (assumed by the blades indicated with a continuous line in FIG. **1** and by reference numeral **6b** in FIG. **2**), in which it defines a dihedral or anhedral angle  $\alpha$  with respect to the main portion **10**; and
- a second position (assumed by the blades indicated with a dotted line in FIG. **1** and by reference numeral **6a** in FIG. **2**), in which it defines a positive or negative sweep angle  $\beta$  with respect to the main portion **10**.

The main portion **10** and tip portion **11** have respective leading **12** and **13** and trailing edges **14** and **15**.

The term dihedral/anhedral angle  $\alpha$  indicates the angle formed between the leading edge **13** of the tip portion **11** and the leading edge **12** of the main portion **10** on a plane parallel to axis **A** and to axis **C**, at the common point of the leading edges **12** and **13**.

An anhedral angle  $\alpha$  indicates that the leading edge **13** of the tip portion **11** is inclined towards the fuselage **2** with respect to the leading edge **12** of the main portion **10**.

Whereas a dihedral angle  $\alpha$  indicates that the leading edge **13** of the tip portion **11** is inclined away from fuselage **2** with respect to the leading edge **12** of the main portion **10**.

The term sweep angle  $\beta$  indicates the angle formed between the leading edge **13** of the tip portion **11** and the leading edge **12** of the main portion **10** in a plane transversal to axis **A**, at the common point of the leading edges **12** and **13**.

A positive sweep angle  $\beta$  indicates that the leading edge **13** of the tip portion **11** is arranged downstream with respect to the leading edge **12** of the main portion **10**, with reference to the direction of motion of the blade **6** about axis **A**.

Whereas a negative sweep angle  $\beta$  indicates that the leading edge **13** of the tip portion **11** is arranged upstream with respect to the leading edge **12** of the main portion **10**, with reference to the direction of motion of the blade **6** about axis **A**.

More specifically, the sweep angle  $\beta$  of the tip portion **11** with respect to the main portion **10** is minimized when the tip portion **11** is arranged in the first position.

The dihedral angle  $\alpha$  of the tip portion **11** with respect to the main portion **10** is zero, when the tip portion **11** is arranged in the second position.

The blade **6** also comprises an actuator unit **16** to produce the transition of the tip portion **11** between the first and second positions.

In greater detail, the actuator unit **16** comprises (FIGS. **3** to **9**):

- a motor **20**;
- a plurality of rods **21** operatively connected to consecutive sections of the tip portion **11** and destined to induce the transition of the tip portion **11** between the first and second positions; and
- a transmission unit **22** functionally interposed between the motor **20** and the rods **21**.

In the case shown, the motor **20** is a stepper motor.

Furthermore, the motor **20** is housed inside the main portion **10**.

The rods **21** rotate about respective axes parallel to each other and to axis **C**, and in turn comprise:

- sections **25** housed in the main portion **10** and extending parallel to the associated axis **C**; and

sections **26** housed in the tip portion **11** and extending along respective axes **D** with respect to axis **C**.

In particular, sections **26** are inclined with respect to sections **25**.

In the case shown, sections **25** and the associated axes **C** are straight, while sections **26** and the associated axes **D** are curved.

In the case shown, sections **26** are shaped in such a way that:

the axes **D** extend, with respect to axis **C**, towards the fuselage **2** when the blade **6** is arranged in the first position (FIGS. **4** to **6**);

the axes extend, with respect to axis **C**, in the opposite direction to that of the motion of the blade **6** when the latter is arranged in the second position (FIGS. **7** to **9**).

Sections **26** are housed in a rotatable manner inside respective apertures **27** defined by ribs **28** of the tip portion **11**.

In this way, the rods **21** are rotatable with respect to the ribs **28**.

Preferably, the rods **21** are connected to the respective ribs **28** by corresponding articulated joints **29** (FIGS. **4-9**).

Furthermore, the rods **21** are axially constrained to the ribs **28** parallel to axis **C** in a manner not shown in detail in the accompanying figures.

Thanks to the mode of constraint between the rods **21** and the ribs **28**, the latter move in a plane orthogonal to axis **C** and their section in this plane does not change during the transition of the tip portion **11** between the corresponding first and second positions, so as not to alter the sections transversal to axis **D** of the tip portion **11**. Whereas the sections of the tip portion **11** interposed between the ribs **28** elastically shear deform in a plane orthogonal to the tip portion **11**.

The ribs **28** are spaced apart along the direction of extension of the tip portion **11**.

More specifically, the section area of the rods **21** transversal to associated axis **D** decreases when proceeding along the tip portion **11** away from axis **A**.

The rods **21** also perform the function of supporting the bending moments and shear loads on the associated blades **6**. In other words, the rods **21** perform the structural function normally carried out by the spars used in the blades.

In the case shown in FIG. **13**, the rods **21** have a circular section in a plane orthogonal to axes **C** and **D**. The diameter of the rods **21** decreases when proceeding along the tip portion **11** following axes **D**.

In the case shown, there are five rods **21** (only some of which are shown in FIGS. **3** to **9**).

The transmission unit **22** comprises, in particular, (FIGS. **3** to **9**):

- a cogwheel **30** connected to an output shaft **31** of the motor **20**;
- a plurality of cogwheels **32** connected to respective rods **21**; and
- a plurality of cogwheels **33** interposed between cogwheel **30** and cogwheels **32**.

The helicopter **1** also comprises a control unit **40** (only shown schematically in FIG. **3**) configured to:

arrange the blades **6** in the respective first positions, when the helicopter **1** is in the hovering condition; and arrange the blades **6** in the respective second positions, when the helicopter **1** is in the forward flight condition.

The tip portion **11** comprises a covering **50** defining the aerodynamic surface.

The operation of the rotor **3** will now be described in detail below.

In particular, the operation of the rotor **3** is described with reference to a single blade **6**, the operation of all the blades **6** being identical.

In the case where it is necessary to maintain the helicopter **1** in hovering conditions, the control unit **40** controls the motor **20** so as to arrange the tip portion **11** in the first position (FIGS. **4** to **6**), where angle  $\alpha$  is anhedral and the sweep angle  $\beta$  is minimized.

In the case where it is required to fly forwards with the helicopter **1**, the control unit **40** controls the motor **20** so as to arrange the tip portion **11** in the second position (FIGS. **7** to **9**), where the dihedral angle  $\alpha$  is zero and the sweep angle  $\beta$  is positive.

The operation of the rotor **3** during the transition of the blade **6** from the first position to the second position will now be described.

The motor **20**, via the transmission unit **22**, causes the rotation of the rods **21** about axis C, by an angle of ninety degrees in the case shown.

This causes a ninety-degree rotation with a circumferential arc trajectory of sections **26** of the rods **21** about axis C.

Since sections **26** of the rods **21** are inclined with respect to the associated sections **25** and can rotate inside the apertures **27** of the ribs **28**, the tip portion **11** deforms.

In particular, the ribs **28** of the tip portion **11** move rigidly, maintaining their shape in planes orthogonal to the axes D as they are in contact with the rods **21**, while the sections of the tip portion **11** interposed between the ribs **28** elastically shear deform.

Referring to FIGS. **16** and **17**, reference numeral **3'** indicates, as a whole, a rotor according to a second embodiment of the present invention.

Rotor **3'** differs from rotor **3** in that it comprises a pair of freewheels **51'** interposed along one of the actuating rods **21'** and configured to prevent rotation of the rods **21'** about axis C in the clockwise and anticlockwise directions, respectively. In particular, it is possible to selectively activate one of the freewheels **51'** and deactivate the other freewheel **51'**.

The operation of rotor **3'** differs from rotor **3** in that it uses, at least in forward flight at speeds above a threshold value, the aerodynamic force acting on the tip portions **11** to move them between the first and second operating positions.

In fact, at speeds above the threshold value, the lift acting on the tip portions **11** varies in sign depending on whether the associated blades **6** are advancing or retreating.

Referring to FIG. **16**, lift is directed downwards when the blades **6** are advancing—i.e. they have respective tangential velocities concordant with the direction of flight of the helicopter **1**—and upwards when the blades **6** are retreating—i.e. they have respective tangential velocities discordant with respect to the direction of flight of the helicopter **1**.

Rotor **3'** uses, jointly with the motor **20**, the downward (upward) lift forces to arrange the tip portions **11** in the first position with an anhedral (dihedral) angle  $\alpha$ , before setting the helicopter **1** in hovering conditions.

In particular, when it is necessary to arrange the tip portion with a dihedral (anhedral) angle  $\alpha$ , the freewheel **51'** that allows rotation in the clockwise (anticlockwise) direction of the rods **21'** is activated and the other freewheel **51'** is deactivated (and vice versa).

The covering **50** also comprises (FIG. **17**) fibres arranged along the associated axes D so that it becomes axially rigid and shear-flexible.

Referring to FIGS. **18** to **20**, reference numeral **3''** indicates, as a whole, a rotor according to a third embodiment of the present invention.

Rotor **3''** differs from rotor **3** in that the tip portion **11''** of each blade **6** (shown entirely schematically) is formed by a plurality of elements **55''** in a rigid material and elements in a viscoelastic material **56''** lying on respective planes orthogonal to axis C and alternating with one another along axis C.

In this way, the tip portions **11** are particularly rigid to flexure in planes orthogonal to axis C so as to maintain the shape of the ribs **28** and therefore the aerodynamic efficiency of the covering **50**, and shear deformable in planes perpendicular to axis C under the action of the rods **21**.

The operation of rotor **3''** is identical to that of rotor **3** and is therefore not described in detail.

Referring to FIGS. **21** to **35**, reference numeral **3'''** indicates, as a whole, a rotor according to a fourth embodiment of the present invention.

Rotor **3'''** differs from rotor **3** in that it does not comprise actuating unit **16** and in that the adjustment of the position of tip portions **11'''** relative to main portion **10** is achieved by means of the resultant moments  $M_r$  generated by inertia forces and aerodynamic forces and/or elastic forces and/or damping forces on respective tip portions **11'''**.

Furthermore, differently from blade **6** of rotor **3**, **3'**, **3''**, the sweep angle of tip portion **11'''** remains constant as blade **6'''** moves between the first and the second position.

In particular, tip portion **11'''** of each blade **6'''** is movable with respect to relative main portion **10** between:

- a relative first angular position, in which it defines anhedral angle  $\alpha$  with respect to relative main portion **10**; and

- a relative second angular position, in which it defines a null angle or a minimized anhedral angle  $\alpha$  with respect to relative main portion **10**.

In the embodiment shown, when set in the first angular position, tip portion **11'''** is arranged at a lower level than in the second angular position.

Blade **6'''** comprises connecting means **60'''** for connecting tip portion **11'''** to main portion **10** movably between the first and second position.

In greater detail, connecting means **60'''** comprises a hinge **61'''** extending about an axis F tangential to axis A and about which tip portion **11'''** is hinged to main portion **10**.

Still more precisely, hinge **61'''** comprises (FIG. **22**):

- a tubular element **105'''** coaxial to axis F;

- a number of protrusion **106'''**, **107'''**, protruding from main portion **10** and axially spaced along axis F, and angularly and axially connected to tubular element **105'''**; and

- a plurality of joining elements **109b'''**, three in the embodiment shown, articulated onto tubular element **105'''** about axis F and protruding from tip portion **11'''**.

Protrusion **106'''** comprises a conical end **108'''** coaxial to axis C and fitted inside a body **110'''** onto which a further joining element **109a'''** is articulated about axis F. Further joining element **109a'''** also protrudes from tip portion **11'''**.

Advantageously, connecting means **60'''** can be selectively set in a first configuration (FIG. **22**) in which they:

- allow the rotation of tip portion **11'''** with respect to main portion **10** in a first angular direction and up to the first angular position; and

- prevent the rotation of tip portion **11'''** with respect to main portion **10** in a second angular direction opposite to the first angular direction.

Furthermore, connecting means **60'''** can be selectively set in a second configuration (FIG. **23a**), in which they:

allow the rotation of tip portion 11''' with respect to main portion 10 in the second angular direction and up to the second angular position; and

prevent the rotation of tip portion 11''' with respect to main portion 10 in the first angular direction.

In the embodiment shown, the first angular direction corresponds to a downwards movement of tip portions 11''' about relative axes C, i.e. to an increase of the anhedral angle  $\alpha$  or to a decrease of dihedral angle.

The second angular direction corresponds to an upwards movement of tip portions 11''', i.e. to a decrease of anhedral angle  $\alpha$  or to an increase of dihedral angle.

Preferably, each tip portion 11''' is set in the respective first angular position, when helicopter 1 is in hover and is set in the respective second angular position, when helicopter 1 is in forward flight.

Furthermore, each tip portion 11''' is movable from the first angular position to the second angular position, when helicopter 1 is in hover or in forward flight with a speed lower than a threshold value and helicopter 1 must be arranged in a configuration optimized for forward flight. Accordingly, connecting means 60''' are set in the first configuration, when helicopter 1 is in hover or in forward flight with a speed lower than a threshold value, and are moved to the second configuration when helicopter 1 must be arranged in a configuration optimized for forward flight.

Each tip portion 11''' is also movable from the second angular position to the first angular position when helicopter 1 is in forward flight and helicopter 1 must be arranged in a configuration optimized for hovering. Accordingly, connecting means 60''' are set in the second configuration, when helicopter 1 is in forward flight with a speed greater than a threshold value, and are moved to the first configuration, when helicopter 1 must be arranged in a configuration optimized for hovering.

In the following of the present description, reference will be made to only one blade 6''', being all blades 6''' identical one another.

Preferably, blade 6''' comprises (FIGS. 22, 23a and 35) a rotational spring 90''', which is interposed between relative main portion 10 and tip portion 11''' and exerts an elastic torque Mk about relative axis F on tip portion 11'''.

In the embodiment shown, spring 90''' elastically preloads tip portion 11''' towards the first angular position.

Preferably, blade 6''' comprises (FIGS. 22, 23a and 35) a rotational damper 92''', which is interposed between main portion 10 and tip portion 11''', and exerts a damping torque Md dependent on the rate of rotation about axis F on tip portion 11'''.

In the embodiment shown, spring 90''' and/or damper 92''' are housed inside body 110'''

Preferably, blade 6''' comprises a plurality of ballasts 91''' arranged on tip portion 11''' and aimed to locate the centre of mass of tip portion 11''' as close as possible to axis F, so as to minimize the moment Mc due to centrifugal force and other inertial actions acting on tip portion 11''' (FIG. 35).

Ballasts 91''' are fixed to main portion 10. In particular, ballasts 91''' are radially opposed radially to axis F with respect to respective joining elements 109a''', 109b'''. In the embodiment shown, ballasts 91''' are made in tungsten.

With reference to FIGS. 27 to 29, it is shown the temporal variation of the lift acting on tip portion 11''' for three different flight condition of helicopter 1.

In the following of the present description, the expression "positive lift" will indicate an upwardly directed lift while the expression "negative lift" will indicate a downward directed lift.

In particular, FIG. 27 shows the temporal variation of lift resulting on tip portion 11''' of blade 6''' in a hover condition of helicopter 1. In this hover condition, the lift is positive and substantially constant in value. Accordingly, the aerodynamic moment Mlift generated on tip portion 11''' by the lift is constant directed in the second angular direction, counter-clockwise in FIG. 35.

FIG. 28 shows the temporal variation of lift resulting on tip portion 11''' of blade 6''' in a forward flight of helicopter 1 with a speed below a threshold value. In this condition, the lift is positive but cyclically changes in value. Accordingly, the aerodynamic moment Mlift generated by the lift on tip portion 11''' is variable and directed in the second angular direction, counter-clockwise in FIG. 35.

FIG. 29 is relative to a forward flight condition of helicopter 1 with a speed above a threshold value. In this condition, the lift acting on tip portion 11''' is cyclically positive and negative (upwards and downwards directed) and changes in value. In particular (see FIGS. 33 and 34): when blade 6''' is advancing (FIG. 34), i.e. is moving towards the front of helicopter 1, tip portion 11''' undergoes a negative lift; and when blade 6''' is retreating (FIG. 33), i.e. is moving towards the rear of helicopter 1, tip portion 11''' undergoes a positive lift.

Accordingly, aerodynamic moment Mlift acting on tip portion 11''' of blade 6''' is directed in the first angular direction, clockwise in FIG. 35, when blade 6 is advancing; and is directed in the second angular direction, counter-clockwise in FIG. 35, when blade 6''' is retreating.

Moments Mlift, Mk, Md, Mc generate a resulting moment Mr about axis on tip portions 11'''. Preferably, spring 90''', ballasts 91''' and damper 92''' are configured to direct resulting moment Mr:

in the second angular direction, when helicopter 1 in hover or in forward flight with a speed lower than the threshold value; and

cyclically in the first and second angular directions (respectively if the blade is advancing or retreating), when helicopter 1 is in forward flight with a speed greater than the threshold value.

Depending on the orientation of resulting moment Mr and on the configuration of connecting means 60''', tip portion 11''' is rotated in the first or in the second angular direction or remains angularly fixed with respect to main portion 10.

In particular, in case resulting moment Mr is directed in the first angular direction and connecting means 60''' are set in the first configuration, tip portion 11''' is rotated up to the first angular position.

In case resulting moment Mr is directed in the first angular direction and connecting means 60''' are set in the second configuration, tip portion 11''' is not rotated.

In case resulting moment Mr is directed in the second angular direction and connecting means 60''' are set in the second configuration, tip portion 11''' is rotated up to the second angular position.

In case resulting moment Mr is directed in the second angular direction and connecting means 60''' are set in the first configuration, tip portion 11''' is not rotated.

Furthermore, blade 6''' comprises a partially relieved stop element 88''', which defines a first and a second stop for tip portion 11''' set in the first angular position and the second angular position respectively.

Preferably, stop element 88' stops tip portion 11''' in the first position at anhedral angle  $\alpha$  of about 20 degrees with

## 11

respect to the plane of main portion **10** and in the second position at a null anhdral angle  $\alpha$  with respect to the plane of main portion **10**.

In greater detail, blade **6** comprises an actuator **65** controllable by a control unit **66** of rotor **3** and which can be operated to set connecting means **60** in either the first configuration or the second configuration.

In greater detail, actuator **65** is housed inside main portion **10**.

Actuator **65** comprises (FIGS. **22** and **23a**):

an electric motor **70** controlled by control unit **66** and having an output shaft **71** rotating parallel to axis F; an output member **73** slidable parallel to axis F; and a transmission group **72** interposed between electric motor **70** and output member **73**.

In particular, transmission group **72** comprises:

a shaft **74** rotatable parallel to axis F, provided with a worm-screw **75** and having a gear **76** at an end thereof;

a gear **77** meshing with gear **76** and arranged at an axial end of output shaft **71**; and

a slide **78**, which is free to slide parallel to axis F, comprises a rack **79** meshing with worm-screw **75** and is integrally movable together with output member **73**.

Output member **73** is housed in a compartment of main portion **10**.

Connecting means **60** comprise, in turn:

a plurality of coupling elements **80** carried by main portion **10** and connected to output member **73**; and a plurality of coupling elements **81a**, **81b** carried by tip portion **11**.

In particular, coupling elements **81a** are arranged at axial ends of tip portions **11** with respect to axis F. Coupling elements **81b** (only one of which is shown in FIGS. **22** and **23a**) are axially interposed between coupling elements **81a** and are spaced along axis F

Coupling element **80** are also axially spaced along axis F.

In particular, each coupling element **80** is axially interposed between one adjacent coupling element **81a** and an adjacent coupling element **81b**, or between two adjacent coupling elements **81b**, or between one an adjacent coupling element **81b** and other one adjacent coupling element **81a**.

Actuator **65** can be operated to alternatively engage coupling elements **80** with first adjacent coupling elements **81a**, **81b** in the first configuration of connecting means **60**, or to engage coupling elements **80** with second adjacent coupling elements **81a**, **81b** in the second configuration of connecting means **60**.

Each coupling element **80** comprises, in turn,

a pair of axial end disks **82a**, **82b** opposite to another and having respective toothed surfaces **83a**, **83b**; and

a pair of one-way freewheel clutches **84**, **85** axially interposed between disks **82a**, **82b**.

In greater detail, surfaces **83a**, **83b** are arranged on respective opposite axial sides of one-way freewheel clutches **84**, **85**.

Furthermore, one-way freewheel clutch **84** allows the rotation of disk **82a** only in the first angular direction and one-way freewheel clutch **85** allows the rotation of disk **82b** only in the second angular direction.

Each coupling element **81b** comprises a pair of axial end disks **86a**, **86b** opposite to another and having respective toothed surfaces **87a**, **87b**.

## 12

Each coupling element **81a** comprises only one axial end disk **86a** having respective toothed surface **87a**.

Surfaces **83a**, **83b** of coupling element **80** face surfaces **87a**, **87b** of coupling elements **81a**, **81b**, which are axially adjacent thereto.

Actuator **65** can be operated to displace coupling elements **80** along axis F:

either up to a first axial position in which surfaces **83a** of disk **82a** mesh with respective surfaces **87a**, **87b** of disk **86a** of first adjacent coupling elements **81a**, **81b** so as to determine the engagement of coupling element **80** and first adjacent coupling element **81a**, **81b**;

or up to a second axial position in which surfaces **83a** of disk **82a** mesh with respective surface **87a**. **87b** of second adjacent coupling elements **81a**, **81b**, so as to determine the engagement of coupling element **80** and second adjacent coupling element **81a**, **81b**.

In the first axial position, one-way freewheel clutches **84** allow tip portion **11** to rotate in the first angular direction relative to main portion **10** and prevent tip portion **11** from rotating in the second direction relative to main portion **10**.

In the second axial position, one-way freewheel clutches **85** allow tip portion **11** to rotate in the second angular direction relative to main portion **10** and prevent tip portion **11** from rotating in the first direction relative to main portion **10**.

In particular, teeth of toothed surface **83a**, **83b** and teeth of toothed surfaces, **87a**, **87b** are shaped in such a way that when toothed surfaces **83a**, **83b** engage respective toothed surfaces, **87a**, **87b**, disks **82a**, **86a** and **82b**, **86b** can rotate integrally with one another about axis F, in both the first and the second angular directions.

The operation of rotor **3** differs from that of rotor **3** in that the angular position of tip portion **11** with respect to main portion **10** is determined by the resulting moment  $M_r$  on tip portion **11** and by the position of connecting means **60**.

The operation of rotor **3** will be now described starting from a flight condition, in which helicopter **1** is in hovering and with reference to a single blade **6**.

In this flight condition, aerodynamic moment  $M_{lift}$  is directed in the second direction when blade **6** is advancing or retreating.

Furthermore, control unit **66** sets actuator **65** in the first axial position. Accordingly, connecting means **60** are set in the first configuration (shown in FIG. **22**), in which they prevent the rotation of tip portion **11** in the second angular direction with respect to main portion **10** and only allow the rotation of tip portion **11** in the first angular direction with respect to main portion **10**.

Accordingly, tip portion **11** is kept in the first angular position in which it defines anhdral angle  $\alpha$  with respect to main portion **10**.

Furthermore, tip portion **11** abuts against stop element **88**, which prevents any further rotation thereof in the first angular direction and any consequent undesired increase of anhdral angle  $\alpha$ .

Being connecting means **60** set in the first configuration, coupling elements **80** engage coupling elements **81a**. Still more precisely, surfaces **83b** of disks **82b** engage surfaces **87a**, **87b** of disk **86a**, **86b** of first adjacent connecting element **81a**, **81b**. Furthermore, one-way freewheel clutch **84** allows tip portion **11** to rotate in the first angular direction relative to main portion **10** and prevents tip portion **11** from rotating in the second angular direction.

In case it is necessary to operate helicopter **1** in forward flight, control unit **66** sets actuator **65** in the second axial position. As a consequence, connecting means **60** are also set in the second configuration (FIG. **23a**), in which they allow the rotation of tip portion **11** with respect to main portion **10** in the second angular direction and prevent the rotation of tip portion **11** in the first angular direction.

Thanks to the fact that connecting means **60** are now set in the second configuration, tip portion **11** increasingly rotates in the second angular direction only, up to when it reaches the second angular position in which the anedral angle  $\alpha$  is substantially null. In the second angular position, tip portion **11** abuts against stop element **88** which prevents any further rotation thereof in the second angular direction and any consequent undesired increase of the dihedral angle.

In particular, being connecting means **60** set in the second configuration, control unit **66** sets actuator **65** in the second axial position (FIG. **23a**).

Therefore, coupling elements **80** engage second adjacent coupling elements **81a**, **81b**. Still more precisely, surfaces **83a** of disks **82a** engage surfaces **87a**, **87b** of disk **86a**, **86b** of second adjacent coupling elements **81a**, **81b**. Furthermore, one-way freewheel clutches **85** allow tip portion **11** to rotate in the second direction relative to main portion **10** and prevent tip portion **11** from rotating in the first direction.

In case it is necessary to operate helicopter **1** in hovering, control unit **66** sets back actuator **65** in the first axial position. As a consequence, connecting means **60** are also set in the first configuration (FIG. **23a**), in which they allow the rotation of tip portion **11** with respect to main portion **10** in the first angular direction only and prevent the rotation of tip portion **11** in the second angular direction.

The increase in the forward speed of helicopter **1** causes at a speed greater than the threshold value:

- a positive lift acting on tip portion **10** of blade **6** both when it advances and retrocedes when the forward speed of helicopter **1** is still lower than the threshold value; and
- a positive lift acting on tip portion **10** of blade **6** when it retrocedes and a negative lift acting on tip portion **10** of blade **6** when it advances, when the forward speed of helicopter **1** is greater than the threshold value.

Accordingly, when the helicopter **1** still is in forward flight with a speed greater than the threshold value, tip portion **11** rotates back in the first angular direction up to when it reaches the first position. This is due to the fact that, being negative the lift on tip portion **11** of advancing blade **6**, resulting moment  $M_r$  on tip portion **11** is directed in the first direction when blade **6** is advancing.

At this point, helicopter **1** is set in hovering.

Referring to FIGS. **36** to **38**, reference numeral **3** indicates, as a whole, a rotor according to a fourth embodiment of the present invention.

Rotor **3** differs from rotor **3** in that each coupling element **80** comprises, in turn:

- an annular frame **95** connected to slide **78** and movable parallel to axis F with slide **78**;
- a pair of axial end disks **82a**, **82b** (**86a**, **86b**) opposite to another and having respective toothed surfaces **83a**, **83b** (**87a**, **87b**);
- a shaft **99** coaxial to axis F; and
- a pair of elements **96** arranged at respective axial ends of shaft **99** and fixed to respective disks **82a**, **82b** (**86a**, **86b**).

In greater detail, teeth of toothed surface **83a**, **83b** and teeth of toothed surfaces **87a**, **87b** are shaped in such a way that when toothed surfaces **83a**, (**83b**) engage respective toothed surface **87a** (**87b**) of first (second) adjacent angular coupling element **81a**, **81b**, the rotation of disk **86a** (**86b**) in the first (second) angular direction causes the intermittent meshing of toothed surfaces **87a**, **87b**.

In particular, the intermittent meshing causes a back and forth movement of surfaces **83a** (**83b**) towards and away from surface **87a** (**87b**) parallel to axis F. Furthermore, teeth of toothed surface **83a**, **83b** and teeth of toothed surfaces **87a**, **87b** are shaped in such a way that when toothed surfaces **83a**, (**83b**) engage respective toothed surface **87a** (**87b**), the rotation of disk **86a** (**86b**) in the second (first) angular direction is prevented.

In the embodiment shown, elements **96** are angularly movable integrally with shaft **99** about axis F and are axially slidable relative to shaft **99** along axis F.

In the embodiment shown, teeth of surfaces **83a**, **83b** and **87a**, **87b** are saw-teeth shaped.

In the embodiment shown, elements **96** are splined on the respective sides facing axis F while shaft **99** is splined on the opposite side with respect to axis F.

Furthermore, each coupling element **80** comprises, in turn, elastic means **100** interposed between frame **95** and elements **96**. Elastic means **100** elastically load elements **96** and disks **82a**, **82b** towards adjacent disks **86a**, **86b** of adjacent coupling element **81a**, **81b**.

In detail, elastic means **100** comprises a plurality of springs **101**, helical springs in the embodiment shown, interposed between frame **95** and elements **96**.

Springs **101** extend along respective axes parallel to axis F and angularly spaced about axis F.

The operation of rotor **3** differs from that of rotor **3** in that the, when connecting means **60** are set in the first configuration (FIG. **36**), toothed surfaces **83a** of disks **82a** mesh with toothed surfaces **87a** of disks **86a** while toothed surfaces **83b** of disks **82b** are axially spaced from toothed surfaces **87b** of disks **86b**.

Due to the shape of teeth of surfaces **83a**, **87a**, the meshing between disks **82a**, **86a** allows the intermittent angular rotation of disks **86a** and, therefore, of tip portion **11** in the first angular direction with respect to disks **82a** and, therefore, to main portion **10**.

This intermittent angular rotation is formed by a succession of alternate first time intervals in which teeth of surfaces **83a**, **87a** mesh with one another and second time intervals in which teeth of surfaces **83a**, **87a** are disengaged.

During the first time intervals, surfaces **83a** rotate in the first angular direction, thus rotating tip portions **11**.

During the second time intervals, surfaces **83a** do not rotate, and the axial disengaging movement of surface **82a** causes the axial movement of elements **96** away from surfaces **83a** and the compression of springs **101**. The subsequent extension of spring **101** causes the meshing of teeth of surfaces **83a**, **87a** of respective disks **82a**, **86a**.

When the connecting means **60** are set in the second angular position, teeth of surfaces **83b**, **87b** mesh with one another, thus preventing the rotation of disks **86b** and, therefore, of tip portion **11** in the first angular direction and allowing the intermittent angular rotation of disks **86b** and, therefore, of tip portion **11** in the second angular position.

From examination of the characteristics of the rotor 3, 3' 3", 3'" and 3'''' and the method according to the present invention, the advantages that can be achieved therewith are evident.

In particular, the tip portion 11 of each blade 6 is selectively movable between:

the respective first position, in which the dihedral/anhe-  
dral angle  $\alpha$  with respect to the main portion 10 is  
non-zero (FIGS. 4 to 6); and

the respective second position, in which the sweep angle  
 $\theta$  with respect to the main portion 10 is non-zero (FIGS.  
7 to 9).

In this way, unlike the known types of rotors described in  
the introductory part of this description, the rotor 3, 3', 3"  
and 3'''' enable both:

having high aerodynamic efficiency when the helicopter 1  
is in hovering conditions and the blades 6 are arranged  
in the associated first positions; and

having low noise when the helicopter 1 is in forward flight  
conditions and the blades 6 are arranged in the asso-  
ciated second positions.

This behaviour, optimized both in hovering conditions  
and in forward flight conditions, is obtained in a particularly  
simple manner and with substantially zero displacement of  
the barycentre of the blades 6 along axes C and D between  
the respective first and second positions.

In this way, the motor 20 does not need to counter high  
loads due to centrifugal force and only needs to generate  
relatively low actuating forces. In consequence, the motor  
20 can be compact and low-cost.

Due to the fact that the transition of the tip portions 11 and  
11" does not result in a substantial variation in the position  
of the barycentre of the associated blades 6 along axes C and  
D, the erroneous operation of one or more of the motors 20  
and therefore the erroneous positioning of the respective tip  
portion 11 and 11" does not cause inertial unbalancing of the  
rotor 3, 3' and 3".

Due to the fact that the motor 20 is housed in the main  
portion 10 and that the sections 25 and 26 of the rods 21 are  
housed in the tip portions 11, the rotor 3, 3' and 3" does not  
alter the aerodynamic profile of the blades 6 and does not  
penalize the overall aerodynamic efficiency of the helicopter  
1.

Finally, connecting means 60'', 60'''' can be selectively set  
in a first (second) configuration in which they allow the  
rotation of tip portion 11'' in the first (or in the second)  
angular direction and up to the first (second) angular posi-  
tion, and in which they prevent tip portion 11''', 11'''' from  
rotating in the second (or in the first) angular direction with  
respect to main portion 10.

In this way, it is possible to move tip portions 11'', 11''''  
between the first and second angular positions, by taking  
advantage of the fact that resulting Mr on tip portions 11''',  
11'''':

is directed in the second angular direction when helicopter  
1 is in hovering or in forward flight with a speed lower  
than threshold value; and

is directed in the first angular direction when relative  
blades 6'' are advancing and helicopter 1 is in forward  
flight with a speed greater than the threshold value.

As matter of fact, when it is necessary to move tip  
portions 11''', 11'''' in the first angular position with the aim  
of increasing the anhedral angle  $\alpha$  thereof, it is enough that  
actuator 65'' sets connecting means 60'', 60'''' in the first  
configuration and that the forward speed of the helicopter 1  
is greater than the threshold value.

Conversely, when it necessary to move tip portions 11'',  
11'''' in the second angular position with the aim of reducing  
anhedral angle  $\alpha$  thereof, it is enough that actuator 65'' sets  
connecting means 60'', 60'''' in the second configuration for  
any hovering condition or forward speed of helicopter 1.

Accordingly, it is possible to adjust the anhedral angle of  
tip portions 11'', 11'''' with respect to main portion 10, by  
simply relying on aerodynamic forces and preferably on  
elastic moment Mk provided by spring 90'' and/or damping  
moment Md provided by damper 92''.

It is therefore no longer necessary to provide a dedicated  
actuating system for adjusting the dihedral/anhedral angle of  
tip portions 11'', 11'''' with respect to main portion 10.

This is particularly advantageous because there is no need  
to transfer large power to rotating blades 6''.

Furthermore, there is no need to provide the necessary  
volume for the actuating system at the interface between  
main portion 10 and tip portions 11'', 11''''. The latter can be  
therefore made in an optimized shape to meet the aerody-  
namic requirements.

Finally, it is also clear that modifications and variants can  
be made regarding the rotor 3, 3', 3'', 3''' and 3'''' and method  
described and illustrated herein without departing from  
defined by the claims.

In particular, the rotor 3, 3' 3'', 3''' and 3'''' could be used  
in a convertiplane instead of in the helicopter 1.

Furthermore, the tip portions 11 and 11" could have  
dihedral angles  $\alpha$  in the respective first positions and nega-  
tive sweep angles  $\beta$  in the respective second positions.

The transmission unit 22 could comprise an epicyclical  
train interposed between the motor 20 and the rods 21.

The actuator units 16 could be completely housed inside  
the tip portions 11 of the respective blades 6.

Rotor 3' might not comprise the transmission unit 22 and  
could comprise a plurality of motors 20 connected to asso-  
ciated rods 21 and not comprise the transmission unit 22.

Finally, as regard to rotor 3'', 3''''', the first and the second  
angular positions of tip portions 11''', 11'''' could correspond  
also to dihedral angles with respect to main portion 10 and  
could be achieved in flight conditions others than the ones  
indicated in the present description.

The invention claimed is:

1. A rotor (3, 3', 3'') for a hover-capable aircraft (1),  
comprising:

a hub (7) rotatable about a first axis (A); and  
at least two blades (6) hinged to said hub (7);

each of said at least two blades (6) comprising a main  
portion (10) hinged to said hub (7) and a tip portion (11,  
11''), which is arranged radially outermost from said  
first axis (A) with respect to the corresponding main  
portion (10);

said tip portion (11, 11'') of each of said at least two blades  
(6) being movable with respect to the corresponding  
said main portion (10) of each of said at least two  
blades (6) between:

a first position defining a dihedral or anhedral angle ( $\alpha$ )  
with respect to the corresponding said main portion  
(10); and

a second position defining a positive or negative sweep  
angle ( $\beta$ ) with respect to the corresponding said main  
portion (10);

characterized in that each of said at least two blades (6)  
comprises at least two actuating rods (21), which are  
operatively connected to the respective said tip portion  
(11, 11'') to cause transition of said tip portion (11, 11'')  
with respect to the corresponding main portion (10);

17

each said at least two actuating rods (21) being rotatable about a second axis (C) and being curved, at least in part, with respect to said second axis (C);  
 said tip portion (11, 11'') comprising at least one rib (28) lying on a plane transversal to said second axis (C) and defining a pair of apertures (27), which are engaged in a freely rotatable manner about said second axis (C) by said respective at least two actuating rods (21);  
 said at least one rib (28) maintaining, in use, respective sections undeformed on planes transversal to said at least two actuating rods (21) during the transition between said first and second positions;  
 the respective sections of said tip portion (11, 11'') interposed between said at least one rib (28) shear deforming, in use, transversely to said tip portion (11, 11'') during the transition between said first and second positions.

2. A rotor according to claim 1, characterized in that: said sweep angle ( $\beta$ ) with respect to the corresponding said main portion (10) is minimized when each said tip portion (11, 11'') is arranged in said first position; and/or  
 said dihedral or anhedral angle ( $\alpha$ ) with respect to the corresponding said main portion (10) is zero when each said tip portion (11, 11'') is arranged in said second position.

3. A rotor according to claim 1, characterized in that said main portion (10) of each of said at least two blades (6) extends along said second axis (C) transversal to said first axis (A);  
 said tip portion (11, 11'') being movable on said plane transversal to said second axis (C) between said first and second positions.

4. A rotor according to claim 1, characterized in that each of said at least two actuating rods (21) comprises:  
 a first section (25) housed inside said main portion (10) of the respective said blade (6) and parallel to said second axis (C); and  
 a second section (26) housed inside said tip portion (11) of the respective said blade (6) and inclined with respect to said second axis (C).

5. A rotor according to claim 1, characterized in that the area of each of said at least two actuating rods (21) measured in cross-section transversal to a direction of extension of the respective actuating rod (21) progressively decreases inside said main portion (10), when proceeding in a direction away from said first axis (A);  
 and/or characterized in that each of said at least two actuating rods (21) perform a structural function of supporting bending and shearing loads acting on each of said at least two blades (6).

6. A rotor according to claim 1, further comprising an actuator (16) that comprises a motor (20) housed inside said main portion (10) of each of said at least two blades (6), and a transmission unit (12) to transmit motion from said motor (20) to said at least two actuating rods (21).

7. A rotor according to claim 6, wherein at least two selectively operable freewheels (51') are operatively connected to each of said at least two actuating rods (21);  
 said at least two selectively operable freewheels (51') enabling the rotation of each said at least two actuating rods (21) in respective mutually opposite directions, following the aerodynamic action acting on the respective said blade (6).

18

8. A method of controlling a rotor (3, 3, 3'') for a hover-capable aircraft (1), said rotor (3, 3, 3'') comprising: a hub (7) rotatable about a first axis (A); and  
 at least two blades (6) hinged to said hub (7);  
 each of said at least two blades (6) comprising a main portion (10) hinged to said hub (7) and a tip portion (11, 11''), which is arranged radially outermost with respect to said first axis (A) with respect to the corresponding main portion (10);  
 said method comprising the steps of:  
 i) arranging said associated tip portions of each of said at least two blades (6) in respective first positions defining respective dihedral or anhedral angles ( $\alpha$ ) with respect to the associated main portions (10), when said hover-capable aircraft (1) is in hovering conditions;  
 ii) arranging said associated tip portions (11, 11'') of each of said at least two blades (6) in respective second positions defining positive or negative sweep angles ( $\beta$ ) with respect to the associated main portions (10), when said hover-capable aircraft (1) is in forward flight conditions;  
 characterized by comprising the steps of:  
 iii) housing at least one pair of actuating rods (21) in a rotationally free manner inside respective through apertures (27) in ribs (28) of said associated tip portions (11, 11'');  
 iv) rotating said at least one pair of actuating rods (21) about a second axis (C) transversal to said first axis (A) to move the associated tip portions (11, 11'') between the corresponding first and second positions;  
 v) maintaining sections of said ribs (28) undeformed in respective planes transversal to said at least one pair of actuating rods (21) during the transition between said first and second positions;  
 vi) shear deforming sections of said associated tip portions (11, 11'') interposed between said ribs (28);  
 said at least one pair of actuating rods (21) comprising respective first sections (25) and second sections (26) inclined with respect to the corresponding first sections (25);  
 said second sections (26) being housed inside said through apertures (27) in a rotationally free manner with respect to said ribs (28); and  
 said ribs (28) lying on respective planes transversal to said second axis (C).

9. A method according to claim 8, characterized in that: said sweep angles ( $\beta$ ) of each said tip portion (11, 11'') with respect to the corresponding said main portion (10) are minimized when each said tip portion (11, 11'') is arranged in said first position; and/or  
 said dihedral or anhedral angles ( $\alpha$ ) of each said tip portion (11, 11'') with respect to the corresponding said main portion (10) are zero when each said tip portion (11, 11'') is arranged in said second position.

10. A method according to claim 8, further comprising step vii) of operating said at least one pair of actuating rods (21) by means of a dedicated actuator (16) or by means of the aerodynamic action acting on said tip portions (11, 11'') during the rotation of said rotor (3''); and/or  
 the step viii) of rotating said tip portions (11, 11'') about said second axis (C).

\* \* \* \* \*